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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  This report is intended to acquaint Naval personnel having limited oceanographic training and experience with an approach to analysis of oceanographic data as applied to acoustic performance predictions. Special emphasis is placed on computer-assisted techniques. The relationship of acoustics and water masses and ocean fronts provides background information for oceanographic analysis. Data requirements, services, and analyses are discussed. ODA, a computer-assisted analysis technique, is also introduced.		

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RP 43

# OCEANOGRAPHIC ANALYSIS MANUAL FOR ICAPS USERS

GORDON G. ANGELL  
LOWELL E. WEBB

SEPTEMBER 1982

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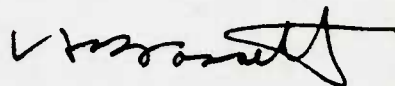
PREPARED BY  
COMMANDING OFFICER,  
NAVAL OCEANOGRAPHIC OFFICE,  
NSTL STATION, BAY ST. LOUIS, MS 39522

PREPARED FOR  
COMMANDER,  
NAVAL OCEANOGRAPHY COMMAND  
NSTL STATION, BAY ST. LOUIS, MS 39529



## FOREWORD

Knowledge of the ocean environment can make the difference between the success or failure of a naval mission. Oceanographic observational data are the basis for an understanding of environmental conditions and their impact on naval operations. Although more observational data can be obtained in a tactical situation now than ever before, such data does not always provide sufficient information to compute reliable tactical indices. Analysis techniques that combine historical characteristics of ocean features and observed data provide a context within which the analyst can identify significant information for further processing into sensor performance estimates and tactical decision aids. This text introduces ocean data analysis techniques designed for tactical applications. Particular emphasis is placed on computer-assisted procedures. Final evaluation is performed by the analyst but automated systems such as the Integrated Command ASW Prediction System (ICAPS) can greatly facilitate the analyst's task.



C. H. BASSETT  
Captain USN  
Commanding Officer

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## I. INTRODUCTION

### A. BACKGROUND

Mission success rates for the U.S. Navy - particularly in the area of antisubmarine warfare (ASW) - can be greatly improved by taking better advantage of the marine environment. From the time combustion engines replaced sails for propelling warships, Naval officers' and warfare specialists' awareness of the significance of the environment in the conduct of war at sea has declined. The major environmental concerns of today's Naval officer relate mainly to the surface conditions of the ocean and their effects on safety of shipping. The conditions immediately below the surface and those extending to the ocean bottom have received little consideration, yet they have a profound impact on the operational performance of acoustic ASW sensors and weapons.

Task group commanders face complex decisions concerning how, when, and where to concentrate forces to best accomplish their missions. Quite naturally these decisions involve such considerations as the nature of the mission, composition of forces, intelligence, threat capabilities, defense envelopes, and weather. Too often the role of the ocean environment is barely considered, or ignored entirely. Yet evidence from Fleet exercises overwhelmingly indicates that allowing for the environment in tactical decision making results in greater overall performance than when the environment is not considered. The successful commander must know what the environmental conditions are in his area of operation. Further, he must understand what those conditions imply in regard to his choice of tactical actions. He must know how the environment affects the performance of his sensors and weapons systems - and how it affects the performance of his adversary's systems.

The acoustic environment can be used to gain a tactical advantage. To achieve the best performance, appropriate sensors must be selected and used in modes that take advantage of natural sound transmission paths. Guidance is available from a number of sources - systems manuals, tactical guides, and sensor performance estimates from shore-based and on-scene computers. The guidance received can be no better than the basic information used in its preparation. Manuals and published guides rely on historical data and average conditions; they give evaluations and recommendations for generalized conditions. Shore-based products are built on extensive data bases that are modified by recent observations. Shore-based products include routine predictions for broad ocean areas and limited time frames, or special request predictions using real-time observations with time lags imposed by communications network and computer-demand loads. For the precise, real-time information needed for critical tactical decisions, the task force commander depends on on-scene computer prediction systems. The specific techniques may differ among the several on-scene systems available, but the general approach is the same as that for the shore-based predictions. Observed data are combined with historical data from a machine-accessed data base, converted to sound speed, and used in a variety of algorithms to compute the performance measures required. The accuracy and usefulness of the resulting predictions are limited by the quality of observed data supplied. Errors may enter the data from equipment malfunction or through the process of transcription; quality control of data input is essential. Errors may result even when accurate observations are made; if the observations are not representative of conditions in the operating area, the results will be misleading. To make the best tactical

decision the commander needs timely, accurate, and representative information. To produce that information, prediction systems require quality data. Preliminary analysis of oceanic data can give the user confidence in the resulting guidance for decision making.

## B. METHODS

Oceanic data analysis may be performed automatically, manually, or by a mix involving man-machine interaction.

Fully automatic (hands-off) screening of input data is employed in some on-scene prediction systems. The technique involves checking the input data for points that fall outside an envelope surrounding a standard curve, usually a climatological mean for the geographic location of the observation. Such a method may be useful in some ocean areas where conditions are stable in time over a broad area. This approach breaks down, however, when significant temporal or spatial variability occurs. Many areas of high strategic and tactical interest are subject to such variability. Observations, however valid, that fall outside the test envelope are either altered, or discarded and historical data substituted. Critical parameters of the acoustic environment, such as the sonic layer depth (SLD), may be misrepresented. Sensor performance predictions derived from these hybrid representations of the environment are unreliable and misleading. The advantages of the fully automated approach are its speed and the minimal demands it makes of the operator.

Manual analysis of oceanic data is often a tedious, time-consuming process. Organized standard techniques streamline the approach and reduce the time required for what is, at best, a laborious effort. Careful plotting and tabulating of the data help identify bad data points or significant changes in water characteristics. Such aids as geographic plots of sea-surface temperature, sonic-layer depth, and temperature on some depth surface, as well as traces of sound speed or temperature versus depth form a basis for sound tactical decisions regarding sensor use. The analyst needs as complete a picture of the present character of the environment as can be compiled within the time and resource constraints of the tactical situation to confidently select the best data on which to base sensor performance predictions. Naval Oceanographic Office Reference Publication RP-20, Oceanographic Analysis Manual for On-Scene Prediction Systems, published in May 1978, is an excellent treatise on manual analysis techniques for specific application to ASW problems. Through use of those techniques the analyst benefits from an intimate knowledge of ocean conditions in the operating area. The chief disadvantages of the manual method of data analysis are the amount of time required to generate the analyses, and the degree of training, skill, and care required to perform the task.

The method presented in this document is based on the same philosophy as the manual approach; that a man can make a better decision by integrating all available information on the environment with his knowledge of the tactical situation than a machine can make using a single observed profile and a retrieved historical profile. The distinction between this technique and the manual approach is that the computer performs the tedious cataloging, sorting,

plotting and graphing of the data, leaving the analyst to interpret the results and make the decisions. Granted, this technique requires more time and skill than the fully automated approach, but the gains in quality and information content of the results far outweigh these drawbacks.

### C. PURPOSE

The value of warfare systems performance predictions depends on how appropriate is the data on which they are based. Deciding how much data is needed to define the environment and which of those data are most appropriate to a given application is thus significant. This document sets out an orderly approach to computer-assisted analysis of ocean data, employing a logical sequence of activities culminating at a decision. When this point is reached, all available oceanic data significantly affecting the decision will have been presented in a way that makes their meaning most clear in relation to the tactical problem.

A background is developed in the oceanographic concepts and properties important to ASW. This background forms part of the knowledge base required to interpret the computer generated displays. The sources of data available to the analyst and criteria for assessing the adequacy of data are addressed.

While the discussion is oriented specifically toward the use of the Oceanic Data Analysis (ODA) program in the Integrated Command ASW Prediction System (ICAPS), the techniques have broad applicability. ODA does not perform the analysis, it is merely a tool to facilitate the analytical process. Everything the program does can be done by hand. Naturally, the computer greatly increases the speed and flexibility with which those functions can be performed.

## II. OCEANOGRAPHY

### A. ACOUSTICS

The principal means of detection used in ASW employs acoustic energy. Water, a poor medium for the transmission of electromagnetic energy, is an excellent conductor of acoustic energy, or sound. Sound is a wave phenomenon, consisting of alternate compression and rarefaction of the medium. The speed of sound, or speed at which the acoustic waves advance through the medium, thus depends on certain characteristics of the medium. Properties of sea water that affect sound speed are salinity, temperature, and pressure. A number of empirical relationships have been derived to express how sound speed varies as these properties change. Generally stated, sound speed increases when salinity, temperature, or pressure increase, as shown in figure 1. The distribution of these properties defines the distribution of sound speed which, in turn, determines the paths sound travels through the water.

Consider, for example, a wave front moving through the water. If the speed of sound is the same everywhere along the front it will continue to move in the same direction at that speed (fig. 2a). If however, the speed of sound varies along the front, as in figure 2b and 2c, the part of the front that experiences higher sound speed will advance faster, moving out ahead of the rest of the front. Since wave fronts always move in a direction perpendicular to their orientation, the direction of motion of the front changes as one part of the front moves ahead. Lines drawn perpendicular to the successive locations of a wave front trace out the paths followed by the front. Such lines are called rays. If sound speed increases with depth (fig. 2b), the deeper portion of the front moves faster and the rays bend upward. If sound speed decreases with depth (fig. 2c), the opposite occurs.

Where sound speed is constant, acoustic energy spreads equally in all directions from the source. A wave front from a small source carries energy outward in an ever-expanding sphere centered on the source. Since no further energy is added to the wave front after it has departed the source, the amount of energy ( $E$ ) borne by the front is unchanged if losses due to absorption and scattering are ignored. The surface of the front, over which the energy is distributed, expands in area. The energy intensity ( $I$ ), or energy per unit area, referenced to the intensity ( $I_0$ ) a unit distance from the source, decreases at a rate equal to the inverse square of the distance ( $r$ ) from the source. This is known as the law of spherical spreading. See figure 3.

Where sound speed varies, the bending or refracting of the ray paths may cause the rays to converge or diverge. A ray-path diagram (fig. 4) shows the effect of a particular sound-speed profile on sound from a source at a given depth. Acoustic energy is concentrated where the rays converge, and detection opportunities are thus increased there. The locations of high likelihood of acoustic detection are dependent on the distributions of the properties temperature, salinity, and pressure that define the sound-speed profile.

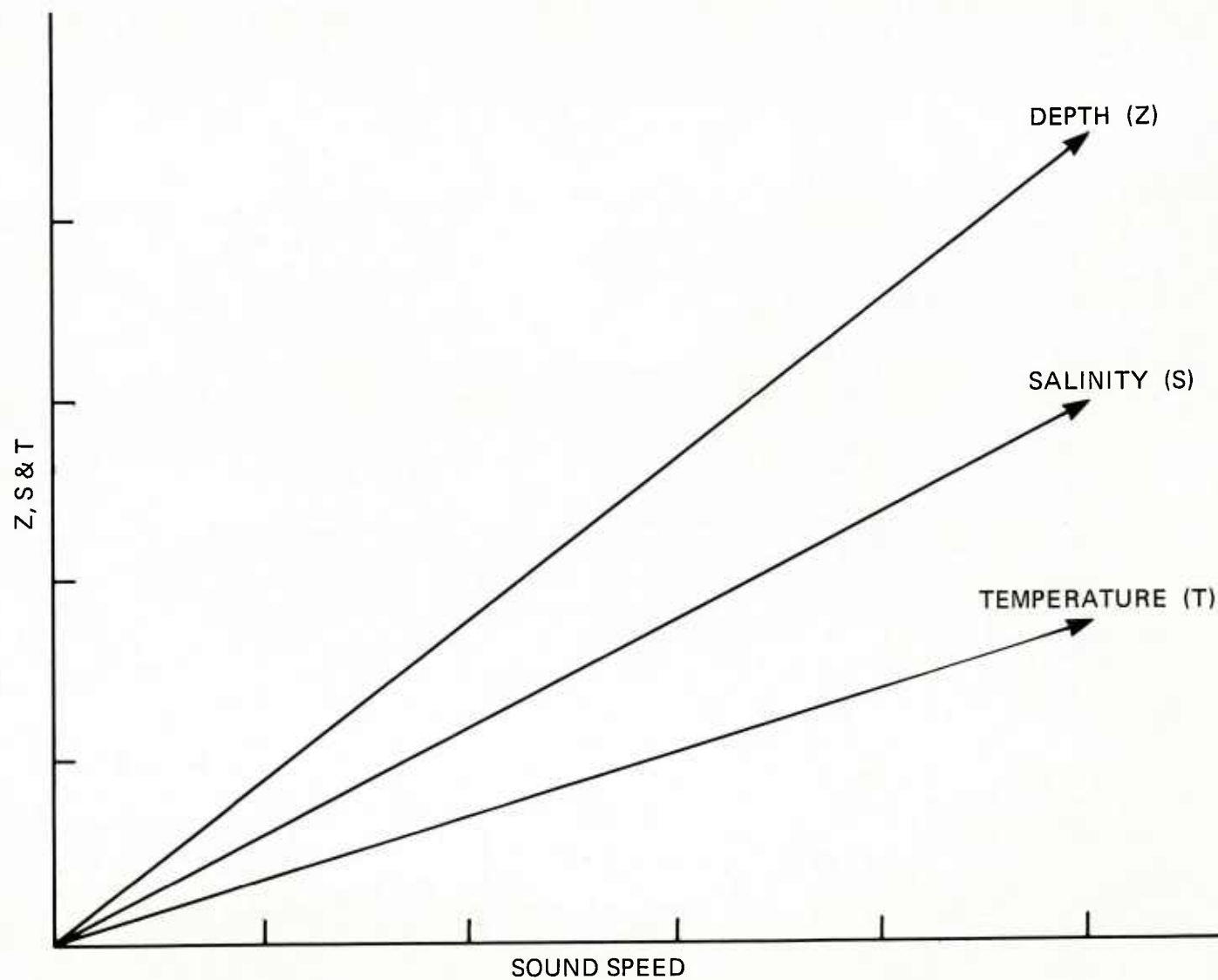


Figure 1. Dependency of sound speed on depth, salinity, and temperature.

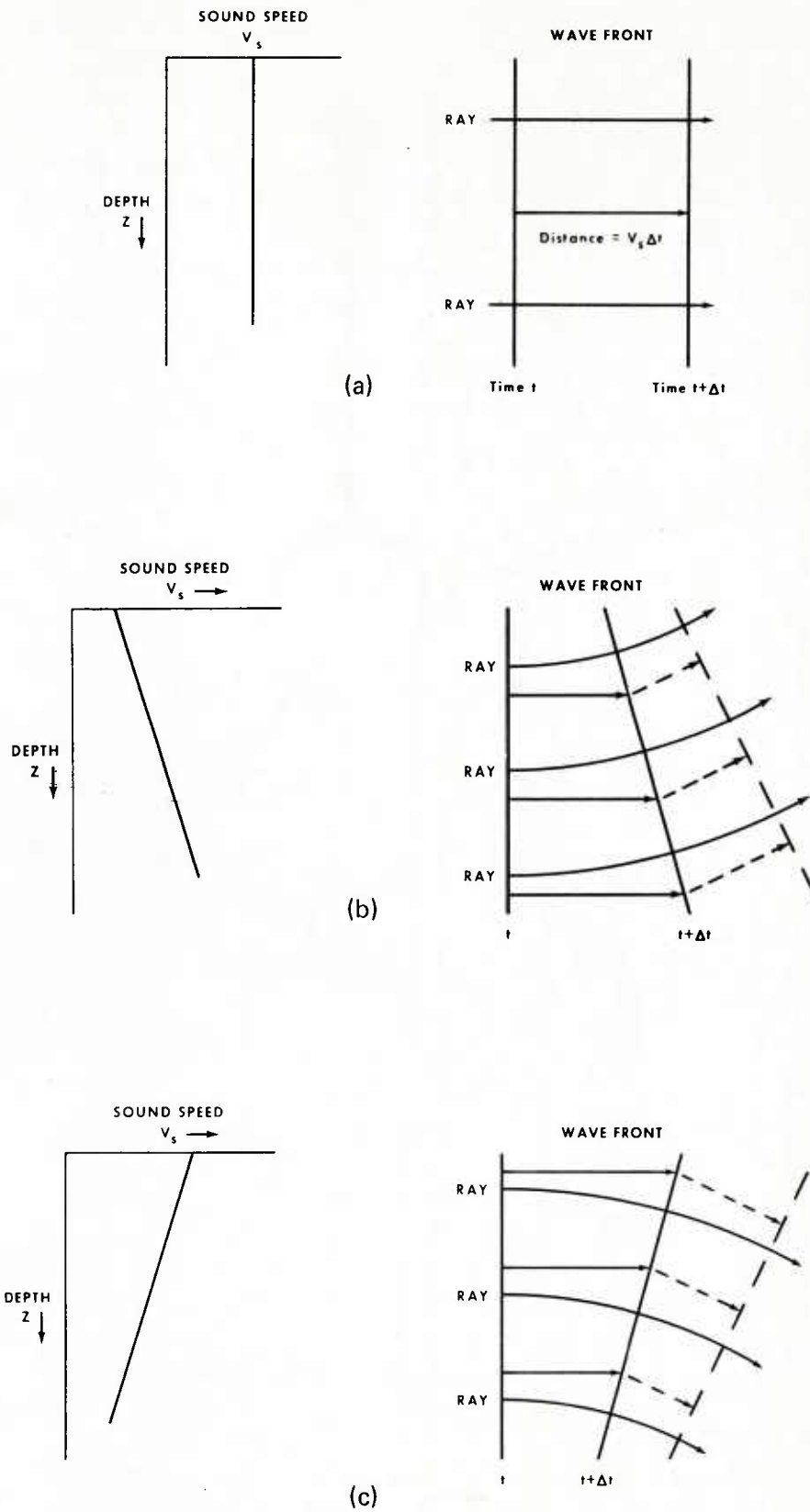
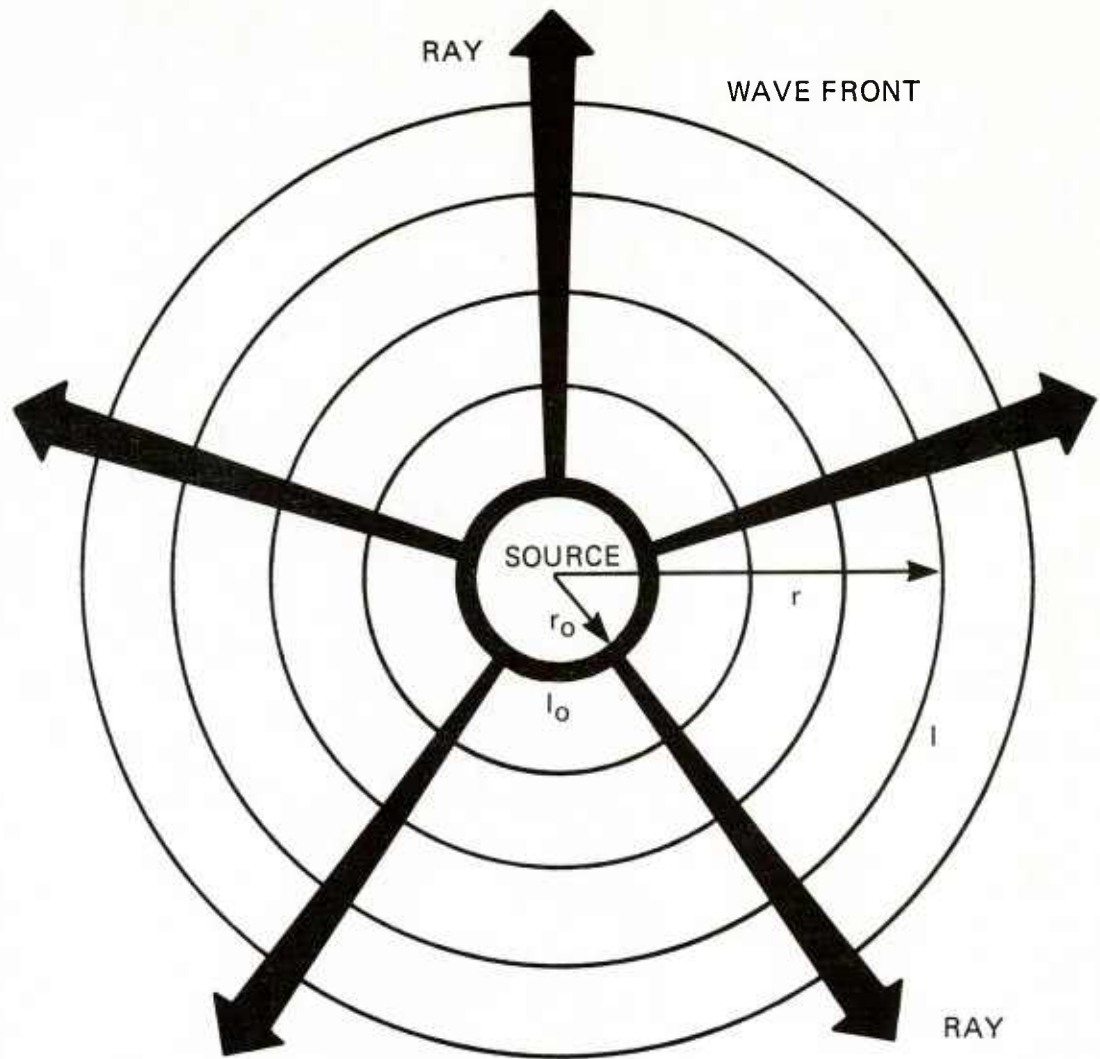


Figure 2. The effect of sound speed gradient on sound ray paths.



$$E = 4\pi r^2 I = 4\pi r_0^2 I_0$$

where  $r_0 = 1$ ,

$$I = I_0/r^2$$

Figure 3. Spherical spreading

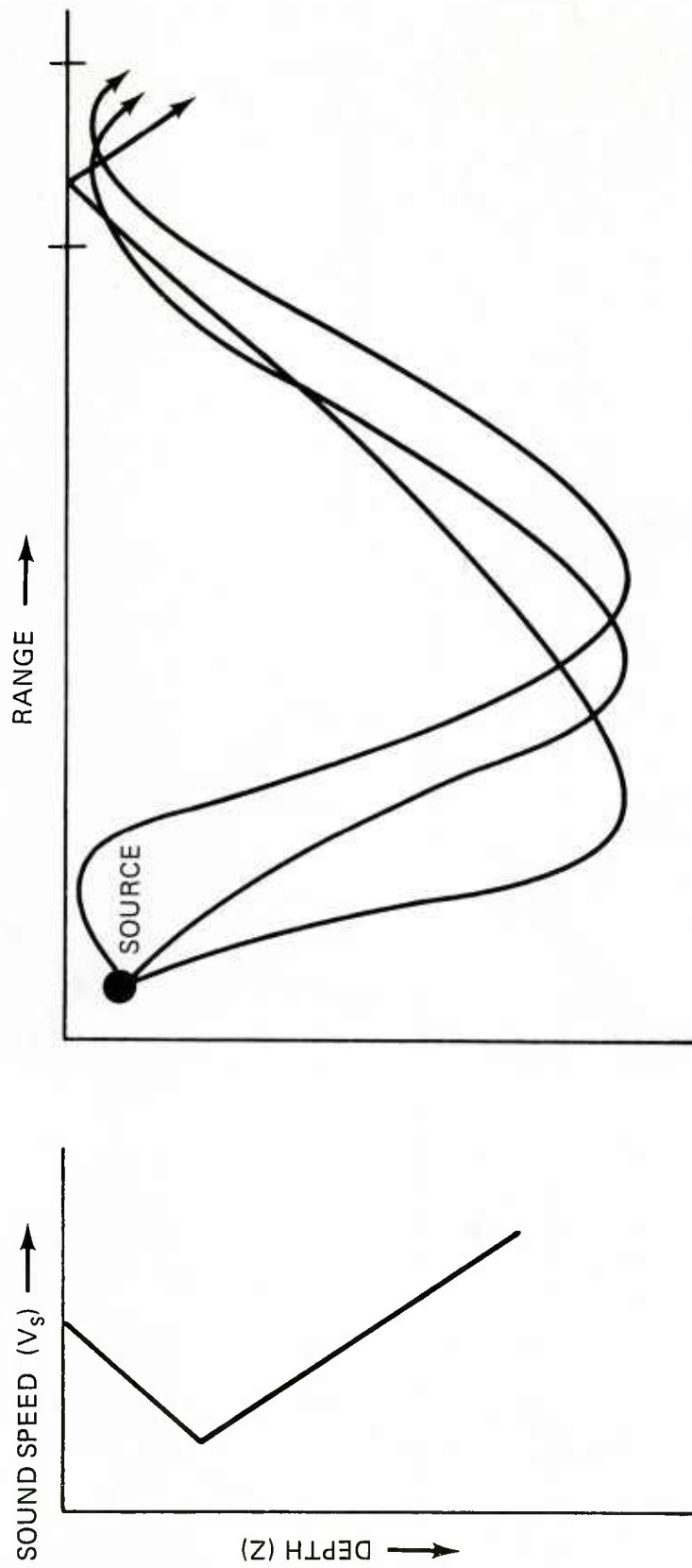


Figure 4. Ray path diagram

## B. WATER MASS CONCEPTS

Pressure increases with depth at a nearly constant rate everywhere in the ocean. The distributions of temperature and salinity thus become of paramount importance in defining sound-speed profiles. Classical oceanography holds that sea water attains its temperature and salinity characteristics at the surface where such influences as solar heating, wind mixing, evaporation, precipitation, river runoff and ice formation occur. This concept has several implications for the use of oceanography in ASW. One is that deep water, below the thermocline and isolated from mixing with surface waters, has stable characteristics which do not change significantly from season to season, or even from year to year. Another is that sampling only the near-surface waters defines the variable portion of the sound-speed profile. Mating these observations with climatological deep-water characteristics yields reliable sound-speed profiles for the entire water column from surface to bottom.

A quantity of sea water having a unique temperature-salinity relationship is called a water mass. This definition which applies to the entire surface-to-bottom water column, differs from the water mass concept of classical oceanography, where a watermass is the result of the mixing of water types, each of which has a single-valued temperature-salinity identity. A water mass may have originated (achieved its particular temperature-salinity characteristics) some distance from where it is observed, or it may have been formed in place. Because water masses migrate, and because the boundaries between them are somewhat dynamic, an observation made at a given location and time may sample any one of several water masses, each with its own distinctive temperature-salinity relationship, and hence its own characteristic sound-speed profile. It is not sufficient to construct a temperature-salinity/sound-speed data base using time-of-year and geographic location alone. It is important that water masses be acknowledged in the building of such a data base. Criteria used to distinguish among water masses that may occur at a given location must be measureable in a tactical situation.

The expendable bathythermograph (XBT) is a tool for measuring the change in ocean temperature with depth. The XBT is available on Navy surface ships, ASW aircraft, and some submarines. It reliably produces temperature readings to depths in excess of 300 meters (984 feet) without interfering with the platforms' other mission-oriented activities. The 200-m (656-ft) level is sufficiently removed from surface meteorological effects that temperature profiles within a given water mass are well defined at that depth. For this reason XBT temperature at 200 m alone is sufficient to discriminate among most water masses. Where adjacent water masses have overlapping ranges of temperature values at 200 m (656 ft), the temperature difference between 200 m (656 ft) and 300 m (984 ft) is a reliable criterion to differentiate between them. The ICAPS data base is structured to consider water masses, and its environmental data processor automatically selects the best water mass match based on characteristics of the XBT input.

Acoustic sensor performance varies from one water mass to another because of the different acoustic characteristics the water masses possess. When the location of water mass boundaries within an operating area are known, acoustic sensor performance predictions representative of each water mass

region can be made. Analysis techniques for locating water mass boundaries using XBT observations are given in section IV.

### C. OCEAN FRONTS

Nearly 30 per cent of the ocean's area is influenced by ocean frontal systems. Fronts are boundaries or narrow zones separating fluid masses (atmospheric or oceanic) of differing densities. The density of sea water is a function of both salinity and temperature. Thus, ocean fronts are narrow zones of strong gradients of either or both of these variables. Usually these zones can be identified by large horizontal temperature gradients. Associated with an ocean front of naval interest is a discontinuity in the acoustic characteristics of the ocean which significantly alters the pattern of sound transmission and propagation loss. Ocean fronts are analogous to the more easily recognized atmospheric fronts. Temperature is the most important regulator of density in the atmosphere. Atmospheric fronts are zones of strong horizontal thermal gradients separating air masses of different temperature. Atmospheric frontal zones are also characterized by significant and often hazardous weather conditions caused by energy exchanges triggered by the movement of air masses over great distances. The movement of water masses in the ocean is much slower than that of air masses in the atmosphere. Consequently, the dynamic processes associated with ocean fronts occur on a much longer time scale than the atmospheric weather. Horizontal current shear associated with ocean fronts is analogous to the wind shift that occurs with a frontal passage in the atmosphere.

The existence of an ocean front can usually be determined by a sharp horizontal temperature gradient at the surface. Fronts may have horizontal temperature gradients of  $1.0^{\circ}\text{C}$  ( $2^{\circ}\text{F}$ ) to  $10^{\circ}\text{C}$  ( $20^{\circ}\text{F}$ ) in a zone of 12 nm (nautical miles). (Temperatures in degrees Celsius may be converted to degrees Fahrenheit by the equation :  $\text{temp } ^{\circ}\text{F} = 1.8 \text{ temp } ^{\circ}\text{C} + 32.$ ) During different seasons of the year the strength of the surface temperature gradient may differ. In the summer, with surface heating and only slight wind speeds to mix the water, the surface temperatures of water masses on either side of a front may approach equal values. The horizontal temperature gradient vanishes. The front is undefined at the surface, but below the surface differences in the water mass properties still exist. The differences between the vertical temperature profiles of water masses persist. These differences may be seen by comparing the vertical temperature profiles on either side of the front. The shape of the vertical temperature profile usually determines the shape of the upper portion of the sound velocity profile. The sound velocity profile governs the paths followed by sound transmitted through the water; hence, ocean fronts can mark the boundaries between distinctly different acoustic regimes in the ocean.

The character, location, and strength of ocean fronts, are often related to currents. Prevailing winds generate currents moving water masses from their origin. The fronts form the boundaries where different water masses converge. Current shears usually exist across fronts. The strength of the front relates directly to the strength of the current. A stronger current will displace a water mass further from its origin and usually into an area of greater contrast. Weak fronts are sometimes found seasonally within an individual water mass. These weaker fronts may be formed by opposing winds such as the prevailing westerlies and the trade winds in low latitudes causing a convergence of slightly different temperatures or salinities.

Ocean fronts vary in strength dependent on the contrast of the opposing water masses. Across a strong front where a temperature difference is well defined, the surface sound velocity change may be greater than 30 m/s (meters per second) (100 ft/s) but it may be less than 15 m/s (50 ft/s) across a weak front. In the water masses on either side of a front, differences in the sonic layer depth of 300 m (984 ft) can exist. The depth of the deep sound channel axis on either side of a strong ocean front can differ by as much as 800 m (2500 ft). These differences are accompanied by changes in the in-layer gradient in the water above the sonic layer depth and changes in the below-layer gradient of the water between the sonic layer depth and the deep sound channel.

The relative strengths can be classified into three general categories shown in the following table:

Relative Strength of Ocean Fronts					
	Sea Surface temperature gradient (°F/nm)	Change in sound velocity (ft/s)	Change in SLD (ft)	Depth (ft)	Persistence
Strong	1.6	100	500	3000	year-round
Moderate	0.2-1.6	50-100	100-500	300-3000	year-round
Weak	0.2	50	100	300	selected seasons only

These categories can be used to look at some typical ocean fronts. The Gulf Stream forms a strong front which dominates the circulation in the western North Atlantic. As the front extends eastward, it weakens to a moderate front. The counterpart in the North Pacific is the Kuroshio Current. The Kuroshio forms a strong front which dominates in the western North Pacific and also weakens to a moderate front as it extends eastward. Both systems are associated with northward moving currents along the western limits of the ocean basin (Beatty, 1981). Along the eastern limits of these ocean basins, the southerly moving currents are not as strong. The associated fronts are weak and seasonal in occurrence. In the southern hemisphere where there is less land mass to influence the circulation, moderate fronts predominate. Figure 5 (Cheney and Winfrey, 1976) shows the distribution of ocean fronts worldwide.

All ocean fronts have some detectable movement in position. Some remain in relatively fixed positions while others meander. Positions vary within predictable limits for each front.

Large-scale eddies are a special case related to ocean fronts associated with meandering current systems. Current meander results from wind stress, earth rotation and shape of the sea floor. Extreme current meanders may form exaggerated loops. When these loops become unstable and separate from the current system, an eddy is formed. In strong ocean current systems

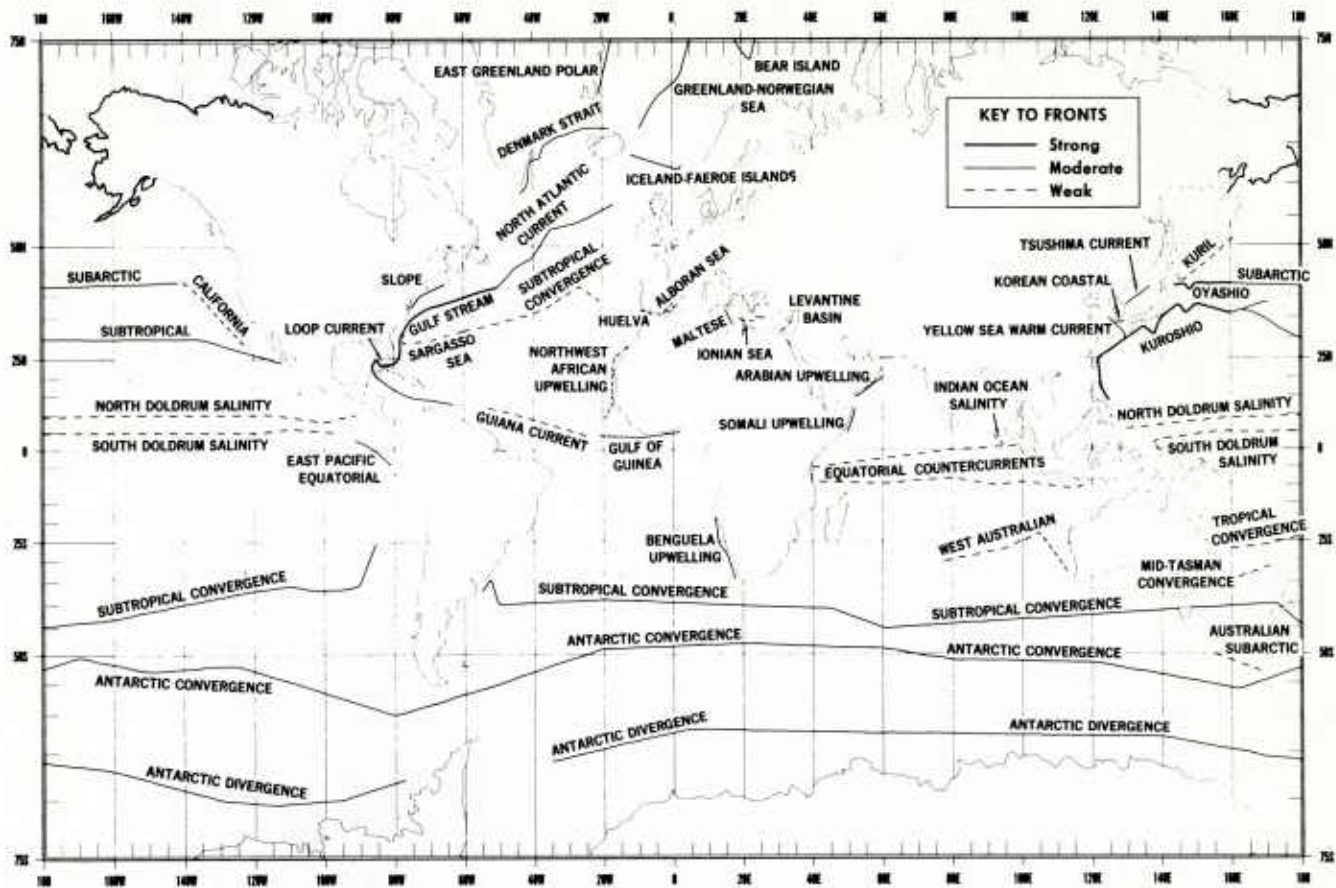


Figure 5. Mean positions of ocean fronts.

characterized by meandering flow, large eddies are frequently formed (fig. 6). An eddy may be described as a rotating water mass trapped inside a circular front. The trapped water mass has different physical properties from the waters outside the bounding front.

Eddies observed in the North Atlantic have diameters of 50 to 200 nm and have a lifespan of up to three years. Maximum surface currents at the boundaries of these eddies are 2-3 knots. The speed falls to zero at the center of the eddy (James and Cheney, 1977). Eddies may rotate clockwise or counterclockwise and may contain warm or cold water relative to surrounding waters. For instance, warm eddies spawned by the Gulf Stream break off into the colder waters north of the stream and spin clockwise. Cold eddies produced by the Gulf Stream rotate counterclockwise and move south of the stream into warmer seas. As the cold eddy penetrates into warm water it eventually sinks to an equilibrium depth. Consequently, the eddy can no longer be detected by surface measurement.

Drifting eddies maintain an independent circulation throughout their lifespan but lose energy with time due to friction and mixing. Eddies are frequently re-absorbed into a current system when they drift too close to the meandering flow. Observations suggest that the movement of eddies is influenced by mean ocean flow. For example, eddies spawned by the Gulf Stream drift 0.2-2 nm/day along paths consistent with the return flow of the Gulf Stream (Richardson, 1976). Figure 7 tracks the movement of a cold eddy after its formation until it approaches entrainment back into the Gulf Stream. The movement of a warm eddy is tracked by the movement of the 15°C (59°F) isotherm at 200 meters (656 ft), figure 8.

#### D. FRONTAL ACOUSTICS

Sensor platforms operating in the vicinity of a significant ocean front must be prepared to encounter differing oceanographic conditions on either side of the front. These varying conditions modify sound transmission. Changes in conditions such as layer depths, sound channels and vertical sound-velocity gradients require different tactics. A prediction of sensor effectiveness for one side of the front is not necessarily valid for the other side. The best sensor spacing and predicted detection ranges may not be the same on both sides of the front. An effective sensor mode or depth on one side may not be effective on the other side of the front. Refraction, or bending of the sound path in the horizontal between a target and a sensor, causes an error in the bearing of the target from the sensor. Bearing errors occur if a sound ray crosses a front at an oblique angle and encounters a difference in sound velocity. Even slight bearing errors are important to long-range detection.

In the vicinity of an ocean front, there may be an increase in ambient noise and reverberation levels. The dynamic processes at the front such as turbulence and upwelling bring nutrients up from deeper water to the photic zone where photosynthesis is responsible for an increase in primary productivity of phytoplankton, resulting in an increase in marine life and its activity. The presence of an abundance of marine life increases the ambient noise and the acoustic scattering. Sea state also contributes to ambient noise levels. When the surface current opposes the wind direction, sea state is increased. When the surface current is nearly parallel to the wind, the sea

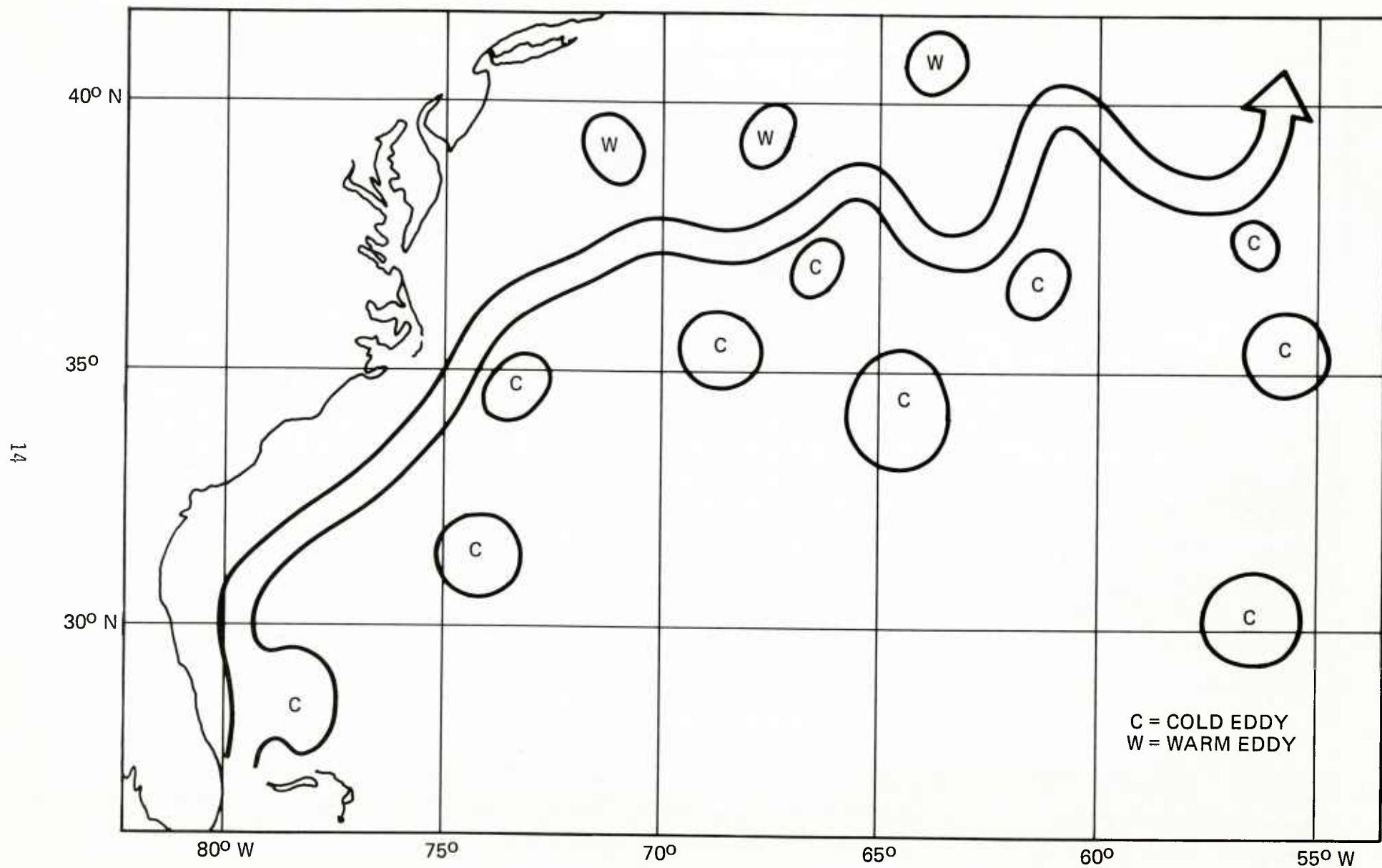


Figure 6. Positions and approximate sizes of Gulf Stream eddies, April - July 1975 (from James and Cheney, 1977).

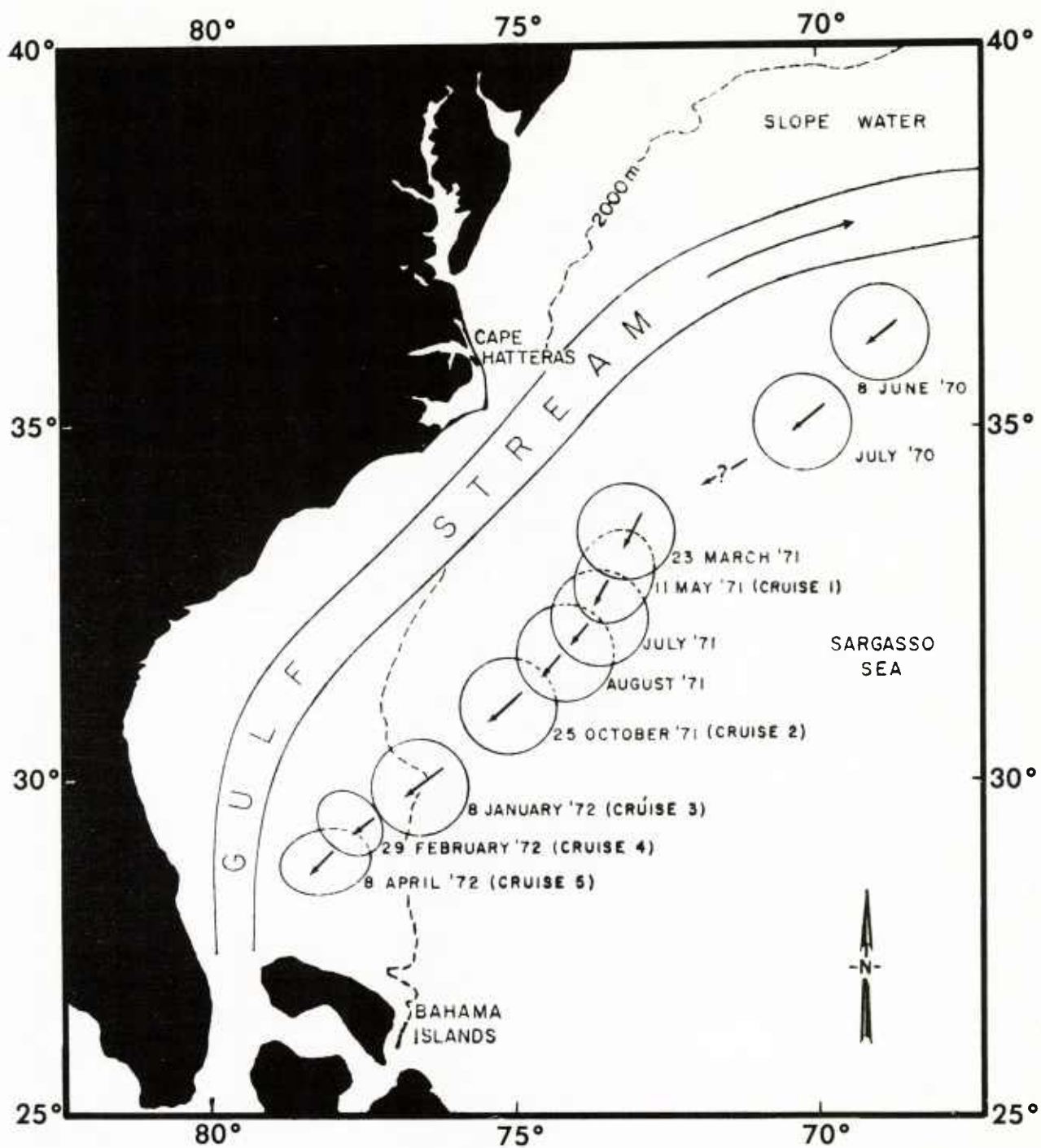


Figure 7. Movement of a cold eddy (from Cheney and Richardson, 1975).

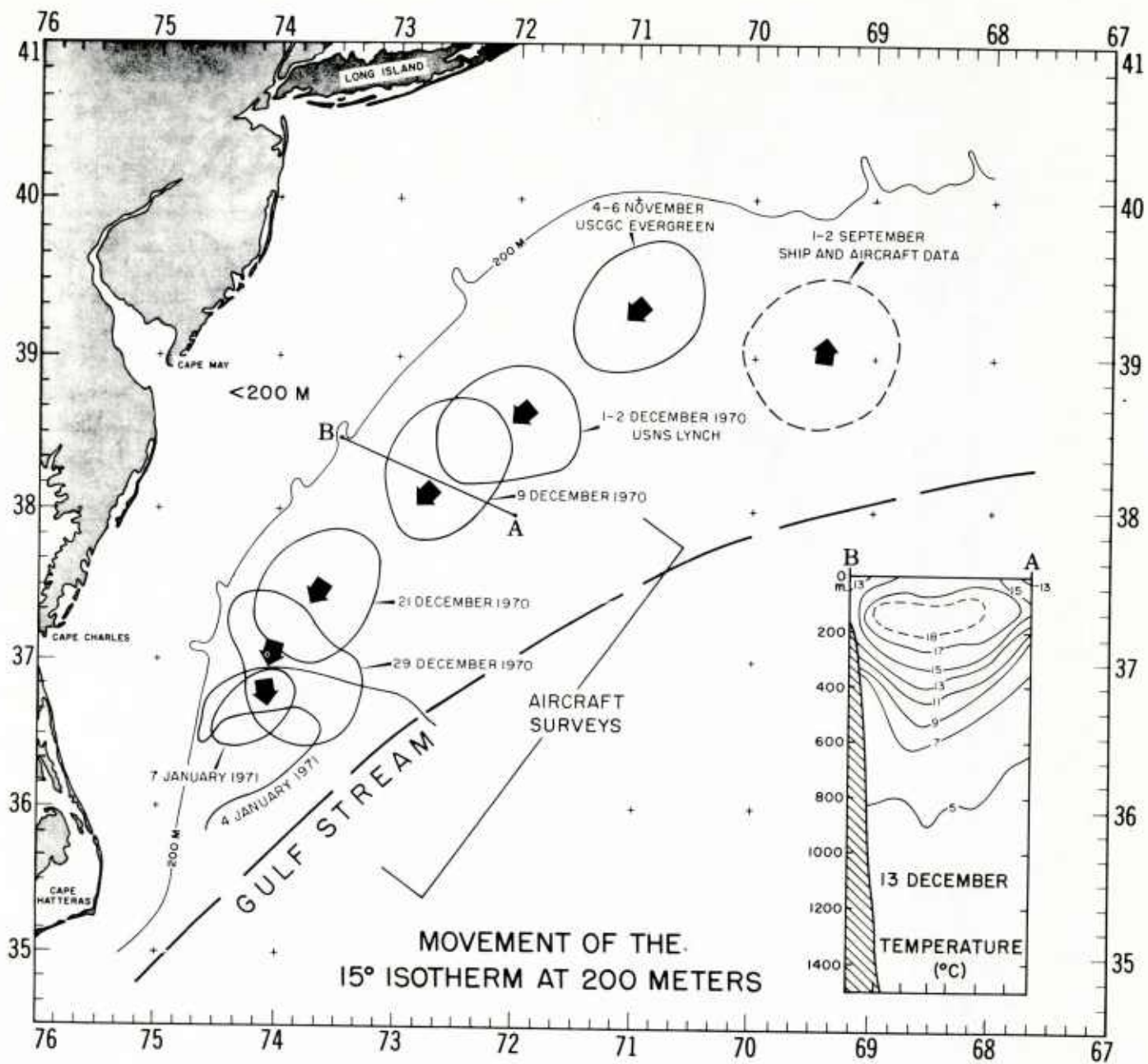


Figure 8. Movement of a warm eddy (from Thompson and Gotthardt, 1971).

state tends to be lower with resulting lower ambient noise. A significant water temperature difference across the front affects the processes of air-sea interaction. The stability of the air just above the water depends on the water temperature. High surface water temperature causes instability of the air which increases the effect of the wind on the surface and results in a higher sea state. Colder water lowers air temperature near the surface and results in stable laminar wind flow. The effect of the wind on the water surface is reduced and a lower sea state results. Thus, different surface water temperatures on either side of a front result in differences in wind-generated ambient noise.

If naval operations are to be conducted in a region where there is more than one water mass, frontal conditions may be encountered. A single BT defines the temperature structure at the location where it was taken. Analysis of the region may be required to determine the extent of the area which the BT represents. More than one BT observation is required to identify a front. The location of a front in the region through analysis of surface temperatures, for instance, will tell the tactician where predictions based on the BT are valid, where such predictions are questionable, and where additional BT observations are needed.

The distribution of fronts and their influence on the effectiveness of ASW sensors make frontal location a tactical concern. Analysis of ocean temperature data to locate frontal positions and strengths is tactically important. Real-time surveillance and analysis of these features is required. Automated analysis techniques assist in this task.

### III. DATA REQUIREMENTS AND SOURCES

A complete and accurate knowledge of the environment as it affects weapons systems, can be translated into a tactical advantage. The ASW tactician, therefore, should use the best data available to him for the generation of tactical decision aids. The data required for acoustic sensor performance predictions fall into several categories and may be obtained from different sources. Which type and source of data is best depends on the situation from which the need stems and on the intended use of the prediction products. This section identifies the various environmental parameters needed for acoustic sensor performance estimates, and suggests appropriate sources from which data may be drawn.

#### A. BACKGROUND

To provide a perspective on the need for data, the basic component of sensor performance computations, the sonar equation, should be considered. The sonar equation expresses an equality between the signal level and the level of background noise that tends to mask the signal. When the signal exceeds the background noise at the sensor, a detection may occur; when background noise exceeds the signal, a detection is unlikely. At the point where the background and the signal are equal, the sensor system is at the threshold of detection. So the sonar equation represents a transition point, where the signal is either emerging from or becoming immersed in the background. The sonar equation takes two forms, one for passive cases, the other for active:

$$\begin{array}{ll} \text{SL-PL} = \text{AN-DI+DT} & \text{(Passive form), and} \\ \text{SL-2PL+TS} = \text{RL+DT} & \text{(Active form)} \end{array}$$

- where
- |                          |   |
|--------------------------|---|
| Source level (SL)        | = the strength of the signal at the source.   |
| Propagation loss (PL)    | = the amount by which signal strength is reduced as the signal passes through the water.  |
| Ambient noise (AN)       | = the sum of noise from all sources other than the source of the signal.  |
| Directivity index (DI)   | = reduction in background noise stemming from the ability of the sensor to focus on sound from one direction.   |
| Detection threshold (DT) | = the ability to pull the signal out of the background; the difference between the values of signal and noise at the sensor when the signal is just detected. |
| Target strength (TS)     | = reflection of incident signal by the target (active).   |
| Reverberation level (RL) | = scattering of sound back toward the source to interfere with the echo from the target (active).   |

The parameters PL, AN, and RL depend on characteristics of the environment. The others are characteristics of the source (be it a sonar or a target), the sensor, and the target.

NAVOCEANCOMINST C3160.4A, Vol. I, Chaps. 8 and 9, provide further details on the active and passive sonar equations.

## B. PROPAGATION LOSS

Propagation loss, or transmission loss, is a function of range from the source. Propagation loss results from the spreading of sound (see Section II.A), absorption of acoustic energy, and scattering of sound out of the path between the source and the sensor. Transmission loss by absorption depends on frequency and the length of the path the sound has travelled, but is not affected significantly by the range of water conditions found in the oceans. Thus no local observations are needed to calculate this contribution to propagation loss. Absorption and scattering by the ocean floor are combined in the single parameter, bottom loss. Bottom loss depends on the nature of the bottom itself; how rough it is, its composition (mud, sand, rock) and the sub-bottom structure. Based on extensive at-sea experiments, empirical equations have been developed that relate loss per "bounce" to sound frequency and grazing angle (the angle at which the sound strikes the bottom). The resulting equations have been correlated to several classifications, or classes, of bottom types identified in ocean surveys. ASW Prediction Area Charts (Naval Warfare Planning Chart Base (NWPCB) Series 2401) list bottom loss classes for the northern hemisphere and the Indian Ocean for frequencies above 1000 Hz. These bottom loss classes, or counterparts for other systems of bottom loss equations and frequency ranges, are contained in data bases for automated acoustic prediction systems. For most cases the bottom loss classes cataloged in computer data bases provide adequate geographic definition. However, when operations take place near boundaries between areas having quite different bottom loss characteristics, use of the charts is prudent because the geographic granularity of the data bases, usually about 30-minute by 30-minute areas, does not permit adequate delineation of the actual boundaries.

Perhaps the most important component of propagation loss is spreading. The manner in which sound spreads outward from the source is controlled by the sound-speed profile. The speed of sound in seawater depends on the temperature, salinity, and pressure (depth). Files of historical values of salinity-temperature-depth or sound speed/depth for seasons or months and geographic areas form part of the data base of all acoustic prediction systems. The historical values are suitable for predeployment familiarization and planning in regard to environmental effects on tactics. For mission planning and tactical support, however, the historical data must be updated with observations to tailor predictions to the actual conditions encountered. The only instruments that can sample the sound speed or temperature-depth characteristics of the ocean without interfering with tactical missions are the expendable sound velocimeters (XSV) and bathythermographs (XBT). The expense and limited availability of XSVs restricts their usefulness, and most prediction systems are not designed to accept the sound speed data they produce. XBTs, however, are almost universally available on Navy ASW ships and aircraft. All acoustic prediction systems have some method to combine observed temperature-depth data with historical data. So XBTs have become a key source of critical data for acoustic predictions.

XBT data are available to the ASW tactician in several forms, each with its advantages and disadvantages. There are direct observations taken by his own platform, or those transmitted from a BT guard ship. The obvious advantage of these is their timeliness. The not so obvious disadvantage is that such observations may not be representative of the waters within the task group formation, let alone of waters that may be encountered farther down track. This disadvantage may be minimized if the analyst knows something about ocean variability in the surrounding area. If variability is slight, there is no problem with using a single XBT to represent the environment. If there are discontinuities such as fronts (see Section II.C above), care must be exercised. Air assets can be used to collect XBT data from distant locations where distinctly different acoustic environments may exist. Another form of XBT for advanced locations may be obtained from the Fleet Numerical Oceanography Center. A composite "BATHY" profile combines all XBT data recently reported from ships and aircraft in an ASW Prediction Area to generate a representative temperature-depth profile for the area. On-scene systems do not now have access to broad reporting networks, so when local observations are not available, historical data must be used. Typical XBT data files are an integral part of the ICAPS data base. These files contain actual XBT observations that represent the near-surface temperature structure for each ICAPS water mass for each month. Hundreds of thousands of XBT observations were analysed statistically and qualitatively to produce this XBT data base. The typical XBTs are a more reliable representation of near surface temperature structure than are seasonal climatic averages.

Other sources of temperature-depth traces include submarine-launched XBTs, sail-mounted thermistors, and thermistors contained in helicopter dipping sonars. Data from submarine sources are of limited availability to ASW forces. Dipping sonar measurements of temperature do not extend deep enough to produce consistently good merges with historical data.

Sea surface temperatures often supply useful clues about water mass distribution and the variability within an area. Such information can be obtained from injection intake thermometers, or from infrared sensors on aircraft or satellites.

Together with the sound speed profile, the depth of the ocean bottom determines what acoustic paths are available for sound transmission. Convergence zone propagation, for example, occurs only if there is sufficient depth to allow the sound to recurve upwards to focus in a near-surface annulus. The configuration of the bottom also is significant. In areas of sloping bottoms, the transition from deep-sound-channel or convergence-zone modes to bottom bounce may provide extraordinary detection opportunities. Bottom depth may be measured by fathometer or read from charts. ASW Prediction Area Charts list mean and mean-deep depths for each prediction area. Bottom depths are also stored as part of the data bases of various acoustic prediction systems. The criteria and geographic granularity by which depths are selected for those data bases vary from system to system. Reference should be made to system documentation to determine what the characteristics are of the bottom depths used.

NAVOCEANCOMINST C3160.4A, Vol. I, Chap. 3, provides further details on propagation loss.

### C. AMBIENT NOISE

Ambient noise is all background noise from sources other than the source of interest - be it the target or a sonar transducer. Wind, waves, precipitation, near and distant shipping, biologics, oil rigs and other industrial activities all contribute to the total noise background in the ocean. The contributions from these sources vary with frequency. Shipping is the major source at low frequencies (below 150 HZ) and sea state the chief source at higher frequencies. Values for ambient noise may be obtained by observation, from standard environmental message products, and from tables, graphs and computer models. Towed arrays, and some sonobuoys and sonars are equipped to measure ambient noise directly. These measurements are not always reliable - in part because of problems arising from equipment calibration, and in part because of high variability, in terms of time and space, in the ambient noise field. Environmental lines in Fleet Numerical Oceanography Center message products, such as Acoustic Sensor Range Prediction (ASRAP), contain ambient noise values at standard frequencies for the ASW Prediction Area for which the forecast is valid. Simple tables and graphs have been produced from which ambient noise values can be extracted on the basis of such parameters as shipping density, wind speed/wave height/sea state, and even location and season. As crude as these empirical devices may seem, the values they give are usually not out of line from observed values or those computed using far more elaborate methods. Independent computer models for ambient noise prediction exist, but more common are auxiliary programs that supply the requirements of specific sensor performance models for ambient noise input. Computer-generated ambient noise predictions are not now readily available outside the research and development community.

### D. REVERBERATION

Reverberation level is a measure of the acoustic energy scattered back toward the source to interfere with the true signal, reflected by the target. Reverberation is of concern, then, only for active sonars. Reverberation results from roughness of the sea surface and bottom, and from the same discontinuities in the water column to which scattering is attributed above.

### E. ENVIRONMENTAL AREA STUDIES

Two series of Naval Oceanographic Office publications, the Environmental Planning Studies (also known as Strategic Strait Studies) and the Environmental Guides, deserve special mention as handy sources of useful oceanographic information. These publications give seasonal and permanent environmental parameters keyed to operating areas in the North Pacific Ocean. They contain information on bathymetry, bottom sediments, high- and low-frequency bottom loss, sound velocity structure, convergence zone transmission, sonic layer depth, propagation loss, sea state, wind, precipitation, ambient noise, surface currents, and oceanic fronts.

#### IV. ANALYSIS

Preliminary analysis of oceanic observations can increase the efficiency and reliability of sensor performance predictions. Use of the analytical techniques that follow reveals the degree of variability in the ocean's thermal and acoustical structure. The boundaries between areas having distinctly different characteristics may be drawn in, and observations representative of each area selected. By reducing the number of samples to be processed to only those needed to describe the tactical environment, analysis reduces the demand for computer processing. Products are available sooner. The user does not have to sort through a confusing array of products; he gets what he needs, when he needs it.

Errors in observations become apparent through comparison to known representative samples. Area plots will rapidly and clearly show the distribution of observations relative to oceanic features that impact the tactical problem. If additional sampling of the environment is needed, it can be concentrated in locations where added data will do the most good.

As a result of such analyses, the tactician can be assured that the predictions and decision aids he receives are built on the best information available. The decision maker can accept those products with high confidence and concentrate his attention toward their implications for tactical actions.

##### A. Data Collection and Quality Control

Tactical commands have limited resources for collecting and processing environmental data into tactical support products. XBTs are purchased with Navy Operations Target (OPTAR) funds and so must compete with spare parts and other expendables for a share of the ship's or squadron's OPTAR allowance. Computer resources for on-scene processing of environmental data into sensor performance estimates and decision aids are shared with tactical systems. The computer time available is not sufficient to convert all observations into prediction products. Even if there were surplus computer resources and all observations were processed, the amount of information would overwhelm the user. For these reasons it is important to have a structured approach to data collection and processing that will guide the sampling process and extract only information critical to decisions at hand.

Advance planning can identify historical features of the operating area environment that impact the performance of acoustic sensors. These water masses, fronts, eddies or other thermal features can be concentrated on by a sampling plan designed to establish the position, extent, orientation and strength of the features. Characteristics of each anticipated feature may be noted for comparison with observations. When complex features are detected, the sampling rate can be increased to define their location and extent. Geographic plots of significant parameters pinpoint where more data are needed. Environmental teams at Naval Oceanography Command Detachments can supply valuable assistance in developing such a plan and putting it into action.

In a carrier task group, for example, one or more ships in the escort force may be assigned XBT guardship duty. These guardships may take XBT observations on an alternating basis according to a schedule established in

advance. COMNAVOCEANCOMINST 3140.1 specifies procedures to complete the standard BATHY message form for reporting XBT observations to the Fleet Numerical Oceanography Center. Information copies of all XBT data reports should be channeled to the local environmental team for insertion into ICAPS. All such messages received should be entered into the Oceanic Data Analysis module of ICAPS to maintain a complete, timely record of the operating environment. If analysis shows a change in temperature structure, additional XBT observations may be specifically requested, or a change in sampling rate made. Air XBT (AXBt) sonobuoys or helicopter dipping-sonar thermistor records may be used to check thermal structure beyond the limits of the task group itself. Such airborne assets are also useful for rapid, detailed sampling of a particular feature.

Careful quality control of XBT data is required to eliminate errors that could mislead users. XBT errors arise from errors in encoding BATHY messages, errors in recording the geographic position of the observation, reading and recording data from the temperature-depth trace at standard depths, and failure to recognize bad traces resulting from malfunctioning XBTs. Most of these errors could be eliminated by more effective personnel indoctrination and training. Environmental team members should provide pre-deployment refresher training to all personnel who will be involved in XBT operations.

Temperature profiles that display characteristics drastically different from surrounding profiles suggest position errors. Comparing the location of such a profile with the positions of recent observations by the same platform is usually sufficient to establish whether the reported location is realistic. If the reported position does not fall near a dead-reckoning track of the platform, and if the source of the error is not obvious and readily correctable, the profile should be discarded.

The structure of existing oceanic data bases requires that the values of parameters at standard depths be used. This practice is justified because the distinctive features of individual observations are already eliminated by the averaging process used to produce the historical profiles. However, when in-situ observations are involved, it is crucial that the character of those observations be preserved. Reading a BT at standard depths destroys the essence of the true temperature profile and often results in misleading estimates of sensor performance. As figure 9 shows, the trace read at standard depths has quite different values of SLD, ILG and BLG from those of the trace read at inflection points. The use of actual inflection points, where the trace displays significant changes in gradient, results in a more accurate representation of the original temperature profile. It cannot be overemphasized that inflection points should always be used for encoding BATHY messages.

XBT systems are simple, rugged and easy to use. Properly maintained and used, they provide accurate, reliable records of ocean thermal structure. However, XBTs are prone to certain malfunctions resulting from extreme conditions, poor handling of probes, mechanical failure, or incorrect adjustment of the recording device. Naval Oceanographic Office Technical Note 3700-75-77, Guide to Common Shipboard Expendable Bathythermograph (SXBt) Recording Malfunctions documents typical failures. Sample traces are given for each common malfunction, together with ways to deal with the problems. Correcting

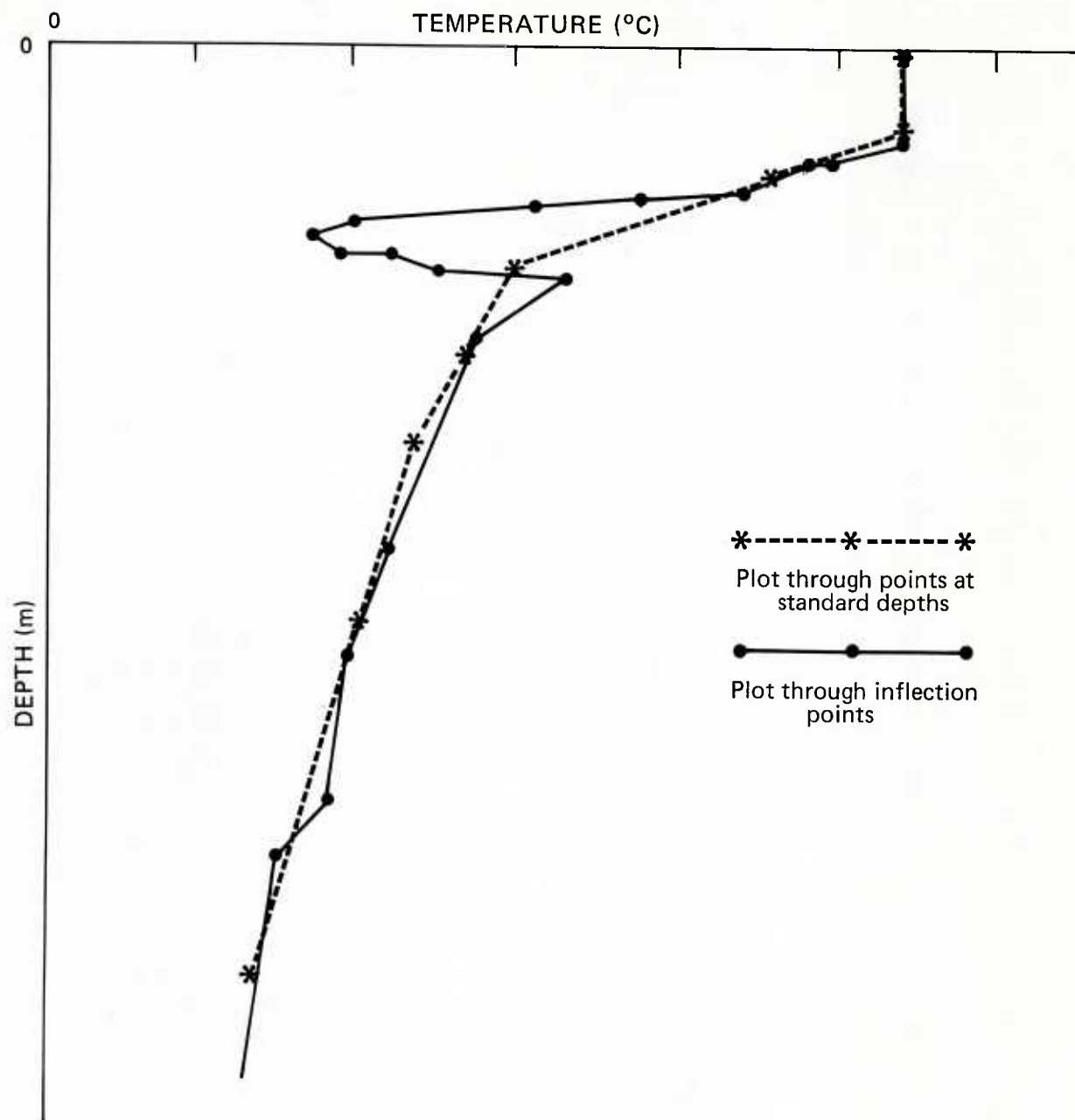


Figure 9. Comparison of bathythermograph traces read at standard depths and at inflection points.

XBT traces that display minor malfunctions is risky business and should not be attempted unless no other data are available.

## B. Analytical Techniques

An oceanographic analyst must determine the salient characteristics of the ocean environment as they relate to the tactical mission. He must identify which XBT profiles should be used to generate acoustic and tactical products. The key elements of the analyst's task are:

- . identify and eliminate erroneous data
- . delineate boundaries between regions having different thermal and acoustic structures,
- . decide where, and how many additional XBTs should be dropped, and
- . select representative XBTs for different water masses,
- . produce descriptive graphics for presenting the environmental analysis in briefings and documents.

This section presents applications of the analysis and display techniques contained in the ICAPS Oceanic Data Analysis (ODA) package. ODA gives the ICAPS user a powerful tool for synoptic analysis of ocean thermal structure and acoustic characteristics. ODA can be used to rapidly store, retrieve, and display data from XBTs. Readers who are concerned about how to execute ODA on the ICAPS computer are referred to the two-volume Program Operating Procedures for the Integrated Command ASW Prediction System, Naval Oceanographic Office Reference Publication 24, Vol. I and II. Complete step-by-step instructions for use of ODA and descriptions of its functions, capabilities and limitations are contained in those documents. The emphasis here is not on how to use ODA to produce analysis products, but on how to use ODA products to gain a better knowledge of the tactical acoustic environment. Although the discussion is keyed to ODA because of the advantages of high-speed data manipulations it offers, all of the following techniques may be adapted to manual applications.

An overview of large-scale features provides a context within which a better understanding of the detailed characteristics of the area of interest can be gained. It is often helpful to get an overview of the data distribution by first displaying a larger area, then shrinking it to the area of particular interest. By initially taking too small an area for analysis, much data may be excluded that would help define the characteristics of the environment. With ODA the user has the option of examining a large area in a general way or a small area in detail. ODA permits viewing analysis areas ranging in size from  $20^0 \times 20^0$  down to  $2^0 \times 2^0$ . The model is thus useful for evaluating alternate track routings across a broad ocean region, for examining local acoustic conditions in relation to prosecuting a specific target, or for a range of applications in between.

The selection of an analysis area acts in effect as a filter on the XBT data base. Other filters, based on time windows or data sources, may also be applied. The choice of a time window is particularly important, since combining observations from different seasons may produce confusing results. Consideration should be given to the dates of changes in meteorological conditions that indicate passage from one season to the next when setting the time span for analysis. A rule of thumb is to use no data older than 30 days in support of current analyses. In any case, ODA does not permit the use of time spans exceeding 90 days.

The identification of each XBT in the ICAPS ODA data file contains a user-assigned code for the platform that collected the data. The platform filter may be used to select or eliminate data from a particular source. The platform filter may be used, for example, to cull out data of doubtful quality or simply to reduce the size of a data set that yields cluttered displays.

When the analysis data set has been defined by use of the area, time, and platform filters, the user is ready to begin analyzing the data. ODA operates on four major categories of data: temperature, sound speed, depth, and gradient. The remainder of this section describes the analyses that may be conducted within each of those categories.

There are environmental parameters of tactical significance such as wave height, ambient noise, scattering coefficients and bottom characteristics that are required to produce acoustic sensor range predictions which have not been considered in the analysis section of this manual because they are not routinely measured from tactical platforms and they do not lend themselves to ODA processing. Fortunately, such parameters are usually of secondary importance relative to the acoustic characteristics of the water which are covered. Where a need exists and data are available, the distributions may be hand-plotted on the same chart base as the ODA plots.

### Temperature Analysis

Temperature analysis may be conducted using either XBT profiles alone, or surface-to-bottom composite profiles consisting of XBT and merged historical data. Ten XBTs in the data set may be selected for display in side-by-side or overlay graphics. Area plots may also be produced to display the geographic distribution of temperatures at a specified depth, or at the depth of a particular feature, such as the base of the sonic layer (SLD). Figure 10 is an XBT locator chart, the result of the area selection and XBT data set filtering process described above. Figure 11a shows the corresponding temperatures at the user-specified depth of 200 m. Such analysis may be performed at any depth from the surface to the bottom; ODA interpolates from the discrete depth-temperature points in the XBT profile to the value for the depth specified. The significance of the 200-m temperature surface is that it can be used with the tables contained in Naval Oceanographic Office Reference Publication 19 to associate the XBT profiles with ICAPS water masses. When the water mass correspondence has been made, the boundaries of water mass regions can be drawn in by hand, as in figure 11b. The acoustic propagation characteristics are usually consistent throughout a water mass region, so that acoustic products based on a representative XBT suffice to describe sensor performance throughout the region. The number of acoustic predictions needed

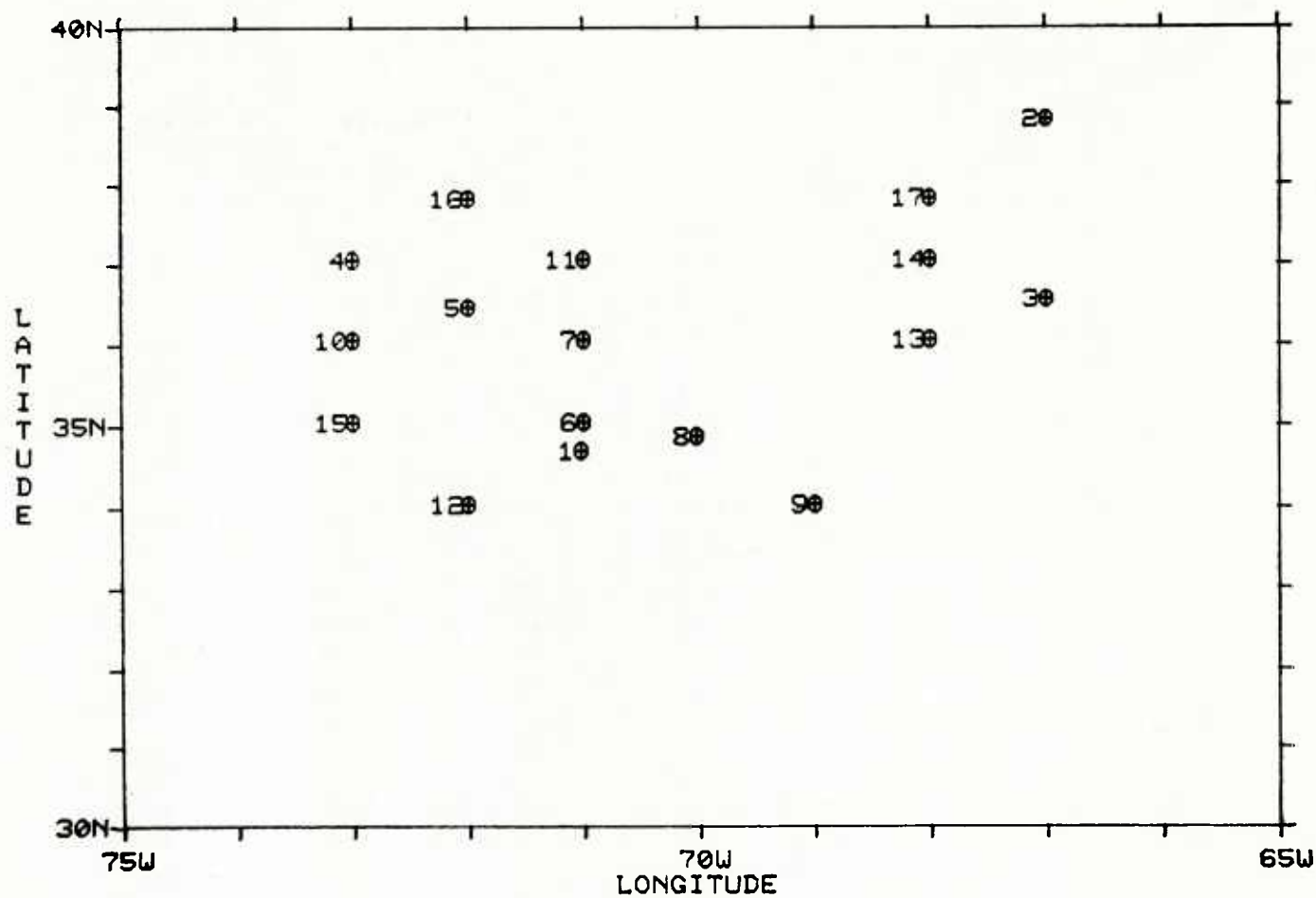
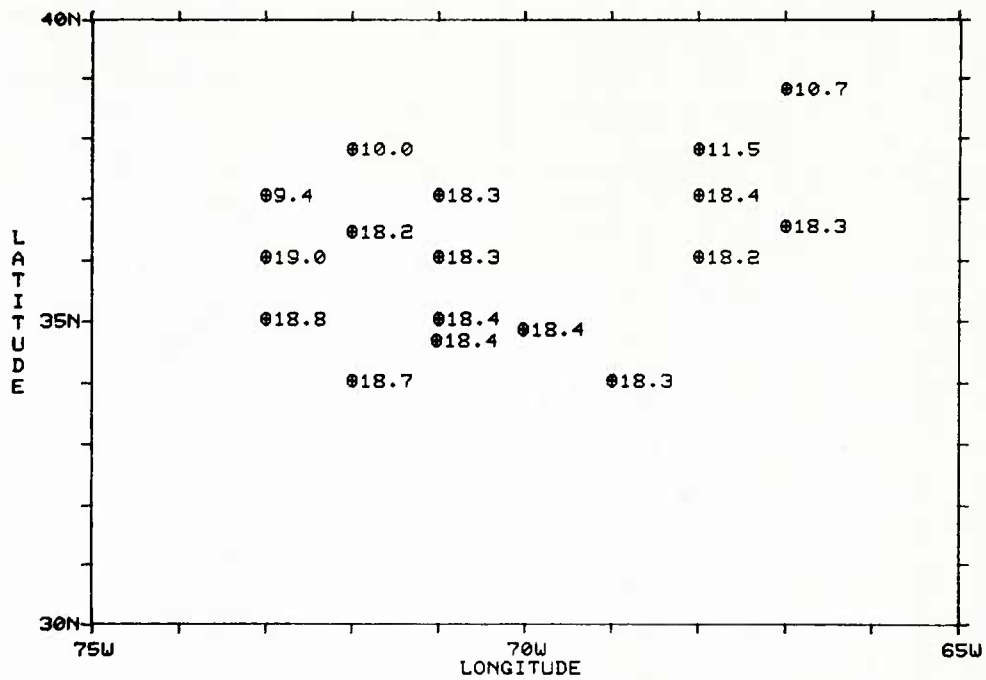
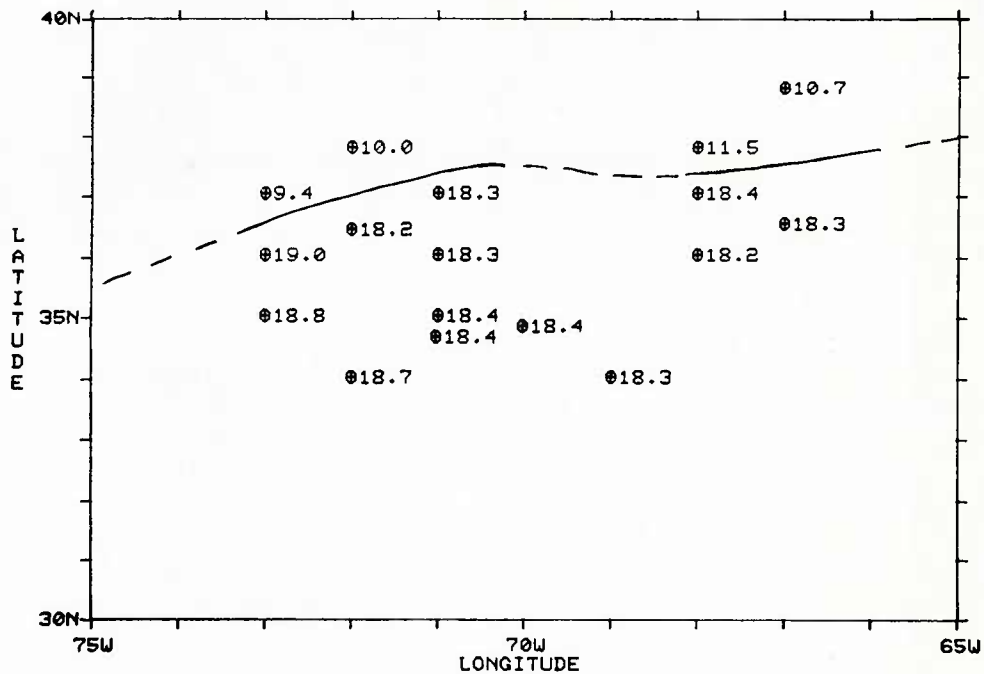


Figure 10. An expendable bathythermograph locator chart.



(a) Temperature at 200 meters for selected bathythermographs.



(b) Temperature at 200 meters, contoured to show separation of two water masses.

Figure 11. Area plots of temperature in (°C).

to portray the spectrum of conditions in the analysis area is, therefore, usually equal to the number of water masses present.

Temperature profiles may also be displayed (fig. 12 a-d). Available ICAPS options include a single profile, side-by-side profiles, profile overlays, and cross-sections. A table of temperature-depth values is supplied with the single profile display, and temperature and depth scales are clearly marked. The scale for side-by-side profile plots varies with the number of profiles displayed; the XBT traces are drawn a constant distance apart along the temperature axis. Quality control is the principal use of this display technique. Departures from the normal shape of the temperature-depth curve show clearly, and the offending XBT is easily identified for further analysis.

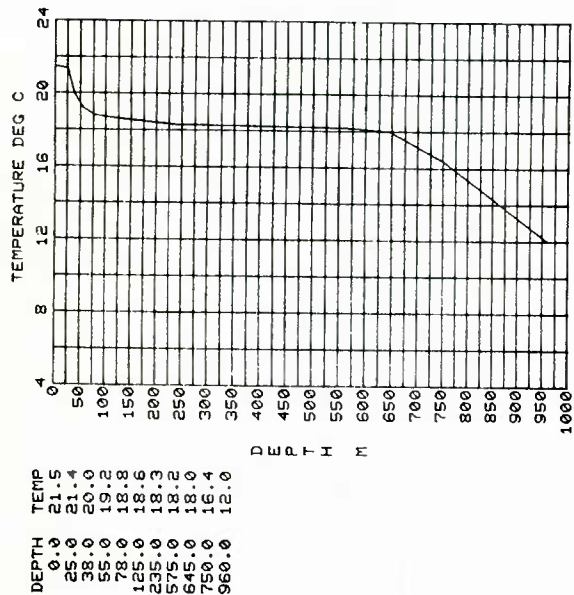
If errors are detected, corrections to the XBT data can be made only by returning the XBT to the ICAPS Profile-Generator (PROFGEN) program. (See Naval Oceanographic Office Reference Publication 24A for this procedure.) Overlay plots are particularly useful for establishing the presence of different water masses. The clustering of profiles in figure 12C, for example, clearly shows the distinct temperature structures of two water masses. Since the characteristics of water masses are usually most distinct in the near-surface layers, XBT overlays rather than overlays of total profiles are better for this purpose. The vertical cross-section gives the user a view of a slice through the analysis area. All XBTs within a distance equal to 1/24 of the larger of the area's latitude or longitude dimensions are plotted in a way that preserves their spatial relationships. The ICAPS user defines the line by specifying endpoints anywhere within the analysis area. The vertical section can be used to view the thermal patterns that will be encountered along the ship's track. Segments of the track where water mass boundaries occur can be noted for planning XBT drop schedules, or to anticipate changes in the acoustic environment.

#### . Sound Speed Analysis

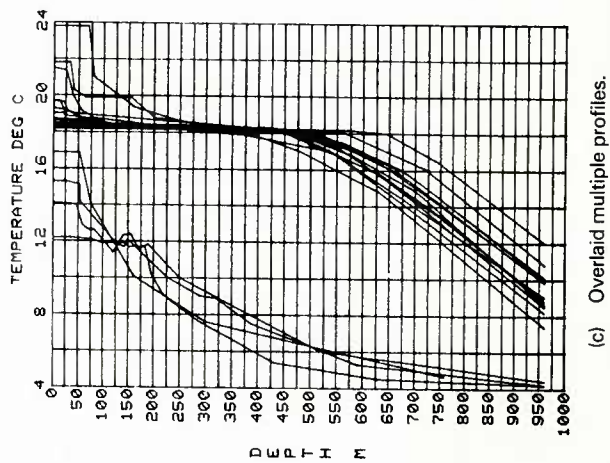
The display options for sound speed are identical to those for temperature. Area point plots of sound speed may be generated for any depth, including SLD (fig. 13). Sound speed profiles may be displayed singly, side-by-side, overlaid, and in cross-section (fig. 14a-d). The uses of these various sound speed presentations are much the same as for their temperature counterparts. The sound speed vertical section conveys additional information if the user develops a facility for visualizing the effect of the changing sound speed structure on ray traces. Deepening or shoaling of the sonic layer or sound channel axis, and changes in sound speed gradients have significant implications for how to use available acoustic assets to best advantage.

#### . Depth Analysis

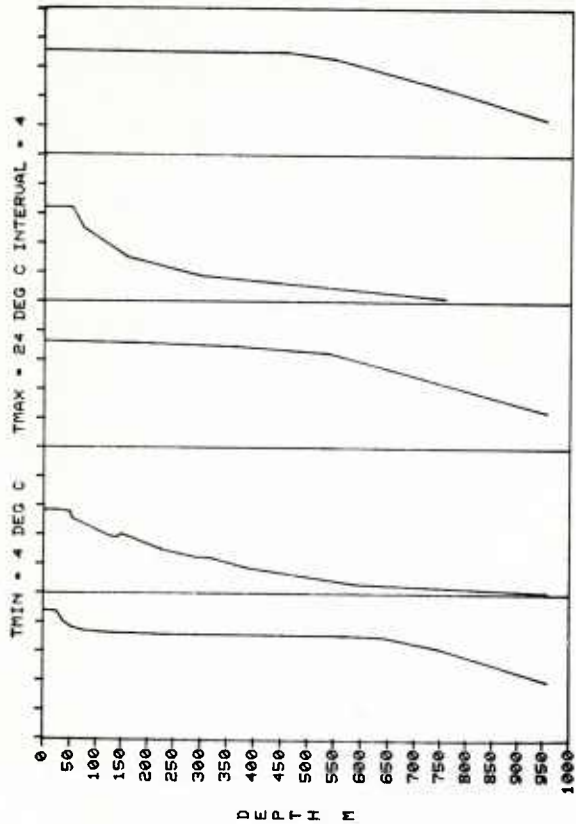
All depth displays are in the form of geographic point plots. Depth options include depth of a specified temperature (deepest occurrence), sonic layer depth, critical depth, depth excess, depth of the deep sound channel axis, and thickness of the deep sound channel (fig. 15a-f). If there are multiple occurrences of a specified temperature, indicating a temperature inversion, the depth of the deepest occurrence is displayed followed by the letter I.



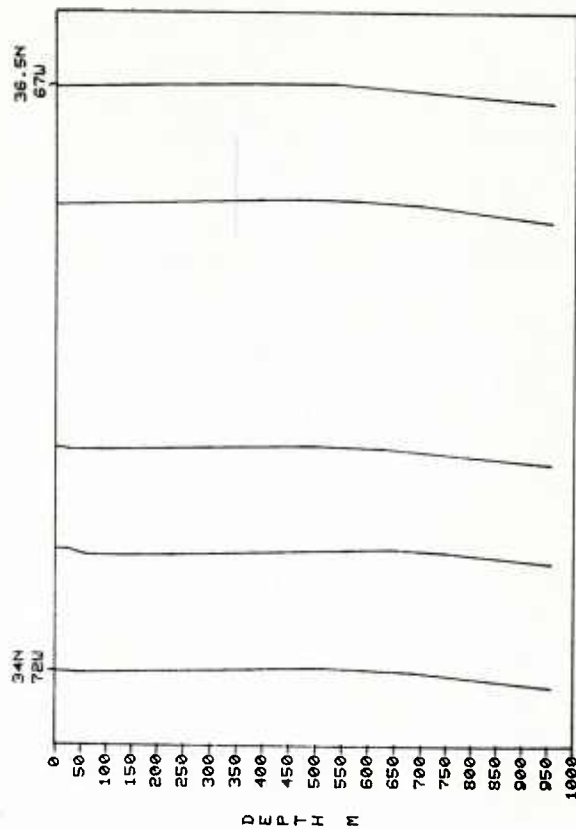
(a) Single bathythermograph profile with listing of temperature at various depths.



(c) Overlaid multiple profiles.



(b) Side-by-side temperature profiles.



(d) Vertical section of profiles along a track.

Figure 12. Vertical temperature profiles showing available ICAPS options.

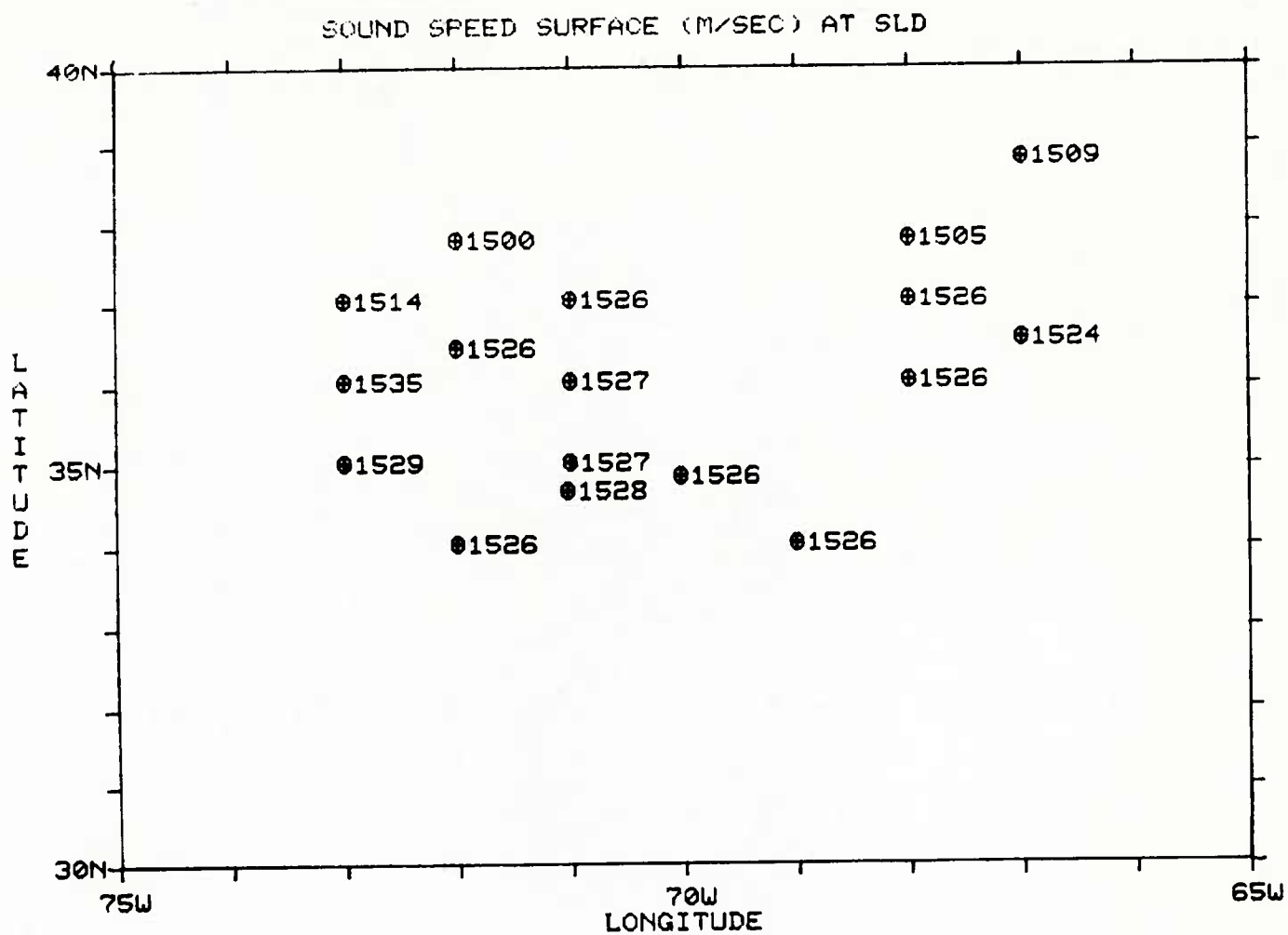
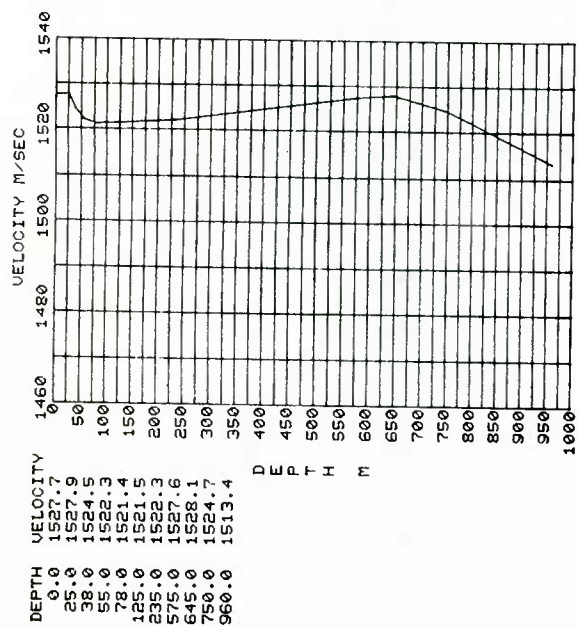


Figure 13. Point plot showing sound speed at the sonic layer depth.



(a) Single bathythermograph profile with listing of sound speeds at various depths.

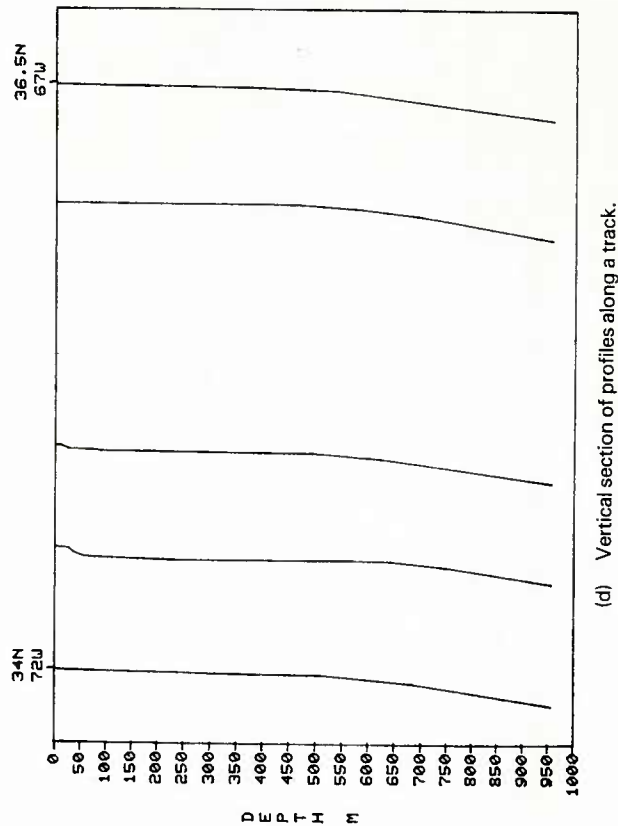
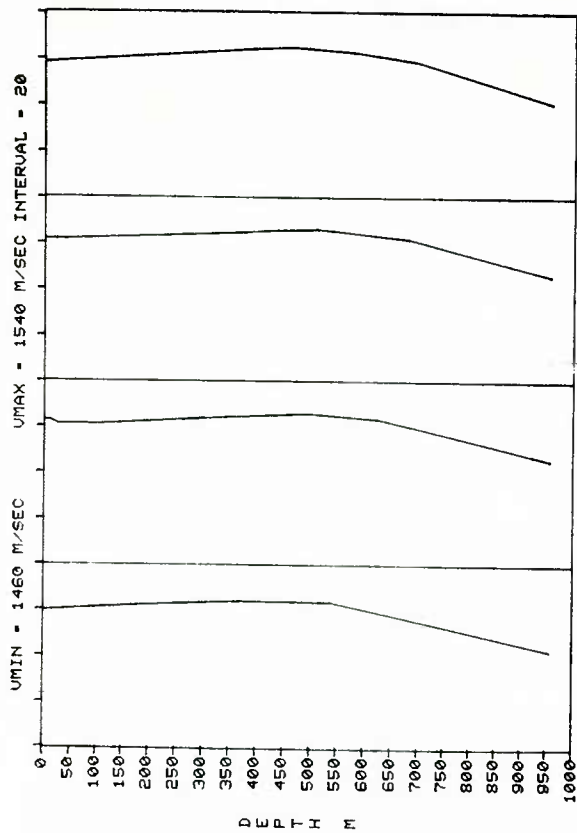
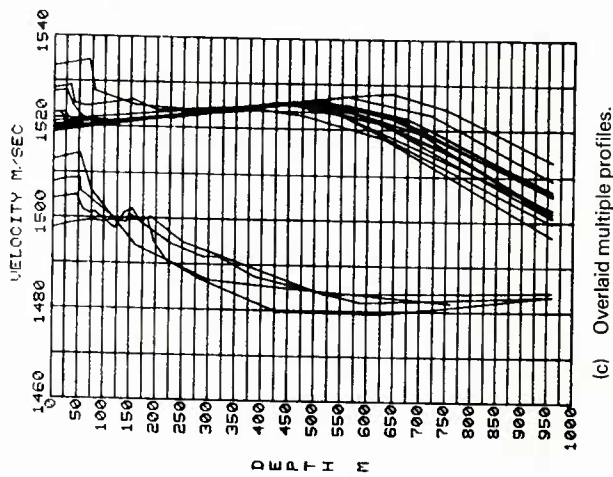


Figure 14. Examples of sound speed profiles.



Under seasonal conditions common in many parts of the world ocean, a surface layer of constant temperature develops as a result of turbulent mixing, primarily due to the effects of wind. Pressure causes sound speed to increase with depth in the layer so that sound is refracted toward the surface where it is reflected downward to be refracted upward again, and so on. Sound trapped in this manner can be transmitted to great distances within a surface duct. The sonic layer depth, together with the in-layer sound speed gradient (see Gradient Analysis below), forms a measure of how effective the surface duct is at trapping and transmitting sound. Low frequency, long-wavelength sound cannot be contained in shallow ducts. The so-called low frequency cutoff for a surface duct can be expressed in terms of SLD. The point plot of SLD thus contains considerable information concerning the effectiveness of shallow sensors in various frequency bands.

Critical depth is defined as the depth below the sound channel axis at which the sound speed reattains the value it had at SLD (or at the surface if there is no surface duct). Taken with the depth excess, which is the difference between the critical depth and the depth of the ocean floor, critical depth indicates whether convergence zone propagation or bottom bounce should be anticipated. The plot of depth excess by itself shows quickly whether the water is deep enough for convergence zone propagation to occur. While published values vary, there is some consensus that 200 fathoms (about 400 m) of water is needed below the critical depth for reliable convergence zone propagation.

The depth and thickness of the sound channel axis tell the user whether the long-range characteristics of the sound channel can be used. In the vicinity of ocean fronts, for example, the sound channel axis shoals and the channel itself may become accessible to sonobuoys or other variable depth sensors. Such depth excursions are of high tactical value and are easily identifiable on the ODA geographic point plot of sound channel axis depth.

### Gradient Analysis

In-layer gradient (ILG) and below-layer gradient (BLG) are measures of the degree of refraction experienced by acoustic energy in the vicinity of SLD. ILG and BLG are presented on geographic point plots like figure 16. The in-layer gradient, in combination with SLD, indicates the strength of the surface duct. That is, the larger the ILG and the deeper the SLD, the more acoustic energy is trapped in the layer and the stronger is the duct. The BLG provides a measure of the direct path range below the layer. The stronger (more negative) the gradient, the shorter the direct path range. The larger the difference between the ILG and BLG, the sharper is the shadow zone between the direct path and the surface duct coverages.

Other gradient analyses, also displayed in the area point plot format, are of interest from a broader oceanographic perspective. The temperature difference between two depths, depth difference between two temperatures, and temperature gradient between two depths do not have direct tactical applications. These measures may be used to refine the oceanographic analysis of an area. An example is the use of the temperature gradient between 200 m and 300 m to distinguish between ICAPS water masses that have overlapping ranges of temperature at 200 m.

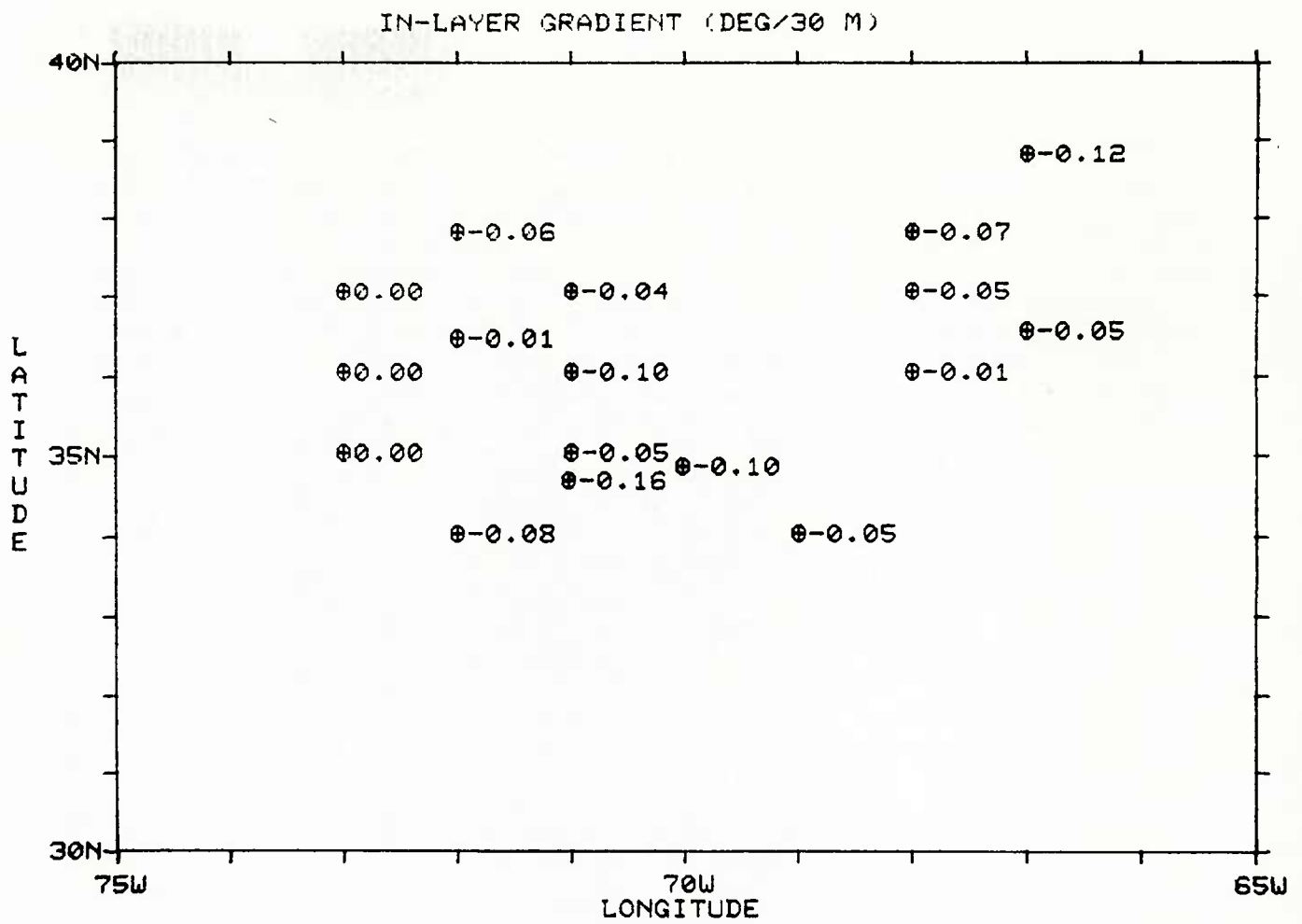


Figure 16. Example of a geographic plot showing the in-layer gradients for selected bathythermographs.

## V. CONCLUSION

The objective of oceanographic analysis in support of on-scene prediction systems is to develop an understanding of the environment that can be translated into tactically meaningful guidance for the conduct of Naval operations. Regardless of whether the analysis is performed by hand or with computer assistance, the increased knowledge of the environment contributes to the potential for mission success. Better acoustic and tactical prediction products result from selection of more representative XBT data on which to base those products. Improved definition of water mass regions within which the sensor performance predictions apply allows tactical actions to be adjusted to remain appropriate and effective under changing environmental conditions. The enhanced appreciation of the environment's effect on the tactician's own force sensors and noise, and on his adversary's, gives him a distinct tactical advantage.

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COMASWINGPAC	1
CNET	1
FLECOMBATRACENLANT (ASWM/ASWOC School)	20
FLECOMBATRACENPAC (ASWM/ASWOC School)	1
FLEASWTRACENLANT	1
FLEASWTRACENPAC	1
NAVPGSCOL	1
NAVWARCOL	1
COMNAVAIRDEVCE (203, Library)	2
COMNAVAIRSYSCOM (370P, Library)	2
COMNAVSEASYSYSCOM (63D5, Library)	2
COMSURFWARDEVGRU	1
COMSUBDEVGRUONE	1
COMSUBDEVRON TWELVE	1
CINCLANT	1
CINCPACFLT	1
NORDA	1
NUSC	1
PROJMR-ASWS	2
USS AMERICA (ASWMOD, METRO)	2
USS CONSTELLATION (ASWMOD, METRO)	2
USS DWIGHT D. EISENHOWER (ASWMOD, METRO)	2
USS ENTERPRISE (ASWMOD, METRO)	2
USS FORRESTAL (ASWMOD, METRO)	2
USS INDEPENDENCE (ASWMOD, METRO)	2
USS JOHN F. KENNEDY (ASWMOD, METRO)	2
USS KITTY HAWK (ASWMOD, METRO)	2
USS MIDWAY (ASWMOD, METRO)	2
USS NIMITZ (ASWMOD, METRO)	2
USS RANGER (ASWMOD, METRO)	2
DTIC	12
ASW OPERATIONS CENTERS	2
Adak, AK	2
Agana, GU	2
Barbers Point, HI	2
Bermuda	2
Brunswick, ME	2
Cecil Field, FL	2
Cubi Point, RP	2
Jacksonville, FL	2
Kadena, JA	2
Keflavik, IC	2
Lajes, AZ	2
Misawa, JA	2
Moffett Field, CA	2
North Island, CA	2
Patuxent River, MD	2
Rota, SP	2
Sigonella, IT	2
NAVEASTOCEANCOMCEN	1
NAVWESTOCEANCOMCEN	1
NAVOCEANCOMCEN GUAM	1
NAVOCEANCOMCEN ROTA	1
NAVOCEANCOMFAC Jacksonville	1
NAVOCEANCOMFAC Keflavik	1
NAVOCEANCOMFAC San Diego	1
NAVOCEANCOMFAC Yokosuka	1
NAVOCEANCOMDET Adak	1
NAVOCEANCOMDET Agana	1
NAVOCEANCOMDET Barbers Point	1
NAVOCEANCOMDET Bermuda	1
NAVOCEANCOMDET Brunswick	1
NAVOCEANCOMDET Cecil Field	1
NAVOCEANCOMDET Cubi Point	1
NAVOCEANCOMDET Misawa	1
NAVOCEANCOMDET Moffett Field	1
NAVOCEANCOMDET Monterey	2
NAVOCEANCOMDET Okinawa, Kadena	1
NAVOCEANCOMDET Patuxent River	1
NAVOCEANCOMDET Sigonella	1

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**OCEANOGRAPHIC ANALYSIS MANUAL  
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**SEPTEMBER 1982**